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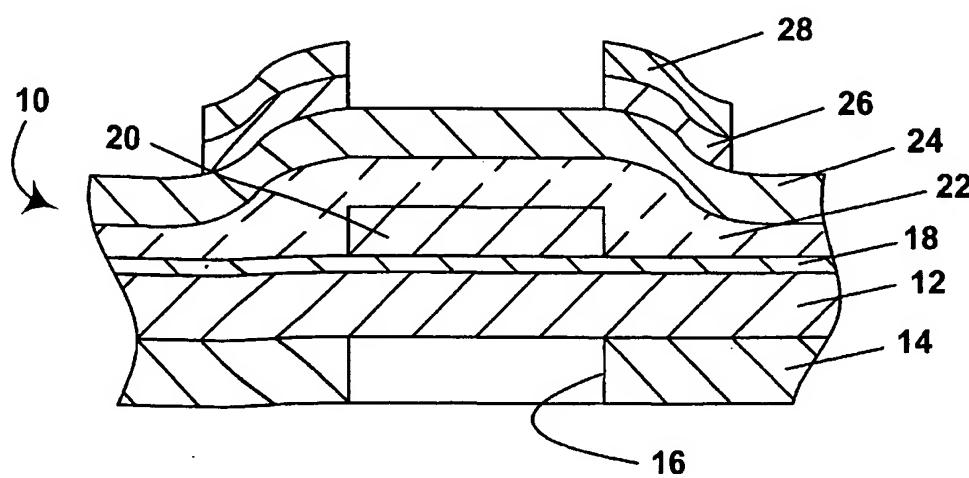
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(54) Title: PROCESS FOR FABRICATING THIN FILM TRANSISTORS



WO 01/80287 A2



(57) Abstract: Transistors are formed by depositing at least one layer of semiconductor material on a substrate comprising a polyphenylene polyimide. The substrate permits the use of processing temperatures in excess of 300 °C during the processes used to form the transistor, thus allowing the formation of high quality silicon semiconductor layers. The substrate also has a low coefficient of thermal expansion, which closely matches that of silicon, thus reducing any tendency for a silicon layer to crack or delaminate.

PROCESS FOR FABRICATING THIN FILM TRANSISTORS

This invention relates to a process for fabricating thin film transistors.

Thin film transistors (TFT's) are known to be useful for, *inter alia*, controlling various types of display; for example TFT's are commonly used to control liquid crystal displays used in portable computers and similar electronic devices. TFT's can also be used to control electrophoretic displays; see, for example, WO-A-00/67327; WO-A-01/08241; WO-A-01/17029; WO-A-01/17040; and WO-A-01/17041. The disclosures of all these applications are herein incorporated by reference.

Although most TFT's have hitherto been fabricated on rigid substrates, there is increasing interest in fabricating TFT's on flexible substrates, especially flexible polymeric films. TFT's fabricated on such flexible substrates could form the basis for large displays which would be light-weight yet rugged, thus permitting their use in mobile devices. TFT's based upon amorphous silicon semiconductors are attractive for use on such flexible substrates since they allow fabrication with a minimum number of process steps and with a low thermal budget. Amorphous silicon transistors have been fabricated on ultra-thin stainless steel substrates (see, for example, Ma et al., *Applied Physics Letters*, 74(18), 2661 (1999)) and on polyimide films (see Gleskova et al., *IEEE Electron Device Letters*, 20(9), 473 (1999)).

However, the polyimide used in the process described in the latter paper, sold commercially under the name "Kapton" (Registered Trade Mark) has a glass transition temperature of only about 300°C, which restricts the temperatures which can be employed during the fabrication process, and results in a less satisfactory amorphous silicon semiconductor layer. This polyimide also has a high moisture absorption (about 4 percent by weight) and such high moisture absorption can result in swelling of the substrate and consequent cracking of thin layers deposited on the substrate, or delamination of thin layers from the substrate.

5 Although stainless steel substrates can withstand process temperatures much higher than 300°C, such substrates require both passivation and planarization steps before transistors can be fabricated thereon. Passivation is required to ensure proper electrical isolation between adjoining metal conductors to be formed on the substrate, and to ensure that potential contaminants within the stainless steel do not diffuse into the transistors. Stainless steel substrates do, however, have the advantages of high dimensional stability and ease of handling in a manufacturing environment.

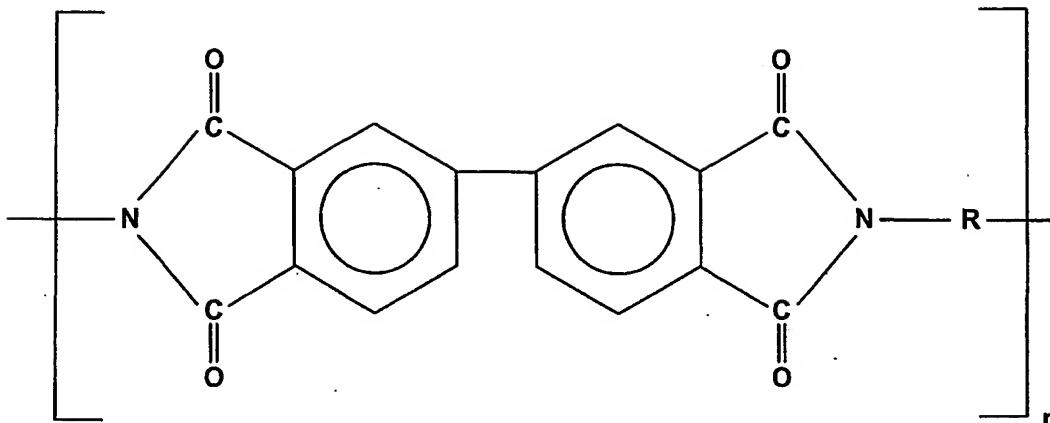
10 It has now been discovered that certain types of polyimides possess properties which render them very suitable for use as substrates in the fabrication of TFT's. These polyimide substrates may be used with or without a metal backing layer.

15 Accordingly, this invention provides a process for forming at least one transistor on a substrate by depositing on the substrate at least one layer of semiconductor material. In the present process, the substrate comprises a polyphenylene polyimide. This process is especially intended for the formation of amorphous silicon transistors, and in such a case the semiconductor material is of course an amorphous silicon.

20 This invention also provides a transistor formed on a substrate comprising a polyphenylene polyimide, the substrate bearing at least one transistor.

25 The sole Figure of the accompanying drawing is a schematic cross-section through a single transistor of a thin film transistor array formed on a polyimide substrate by the process of the present invention.

30 Preferred polyphenylene polyimides for use in the present process are those sold commercially under the trade names Upilex-S and Upilex-VT by UBE America, Inc., 55 East 59th Street, 18th Floor, New York NY 10022, United States of America. Both these materials are stated by the manufacturer to be of the formula:



in which R is an alkylene group. These polyimides are derivatives of biphenyl-3,3',4,4'-tetracarboxylic acid and an α,ω -alkanediamine, for example 1,6-hexamethylene diamine (formally hexane-1,6-diamine). The main difference 5 between the two materials is that Upilex-S is a simple polyimide film, while Upilex-VT is surface-treated on one face to facilitate hot lamination of the film, without adhesive, to ceramics or metal foils. For purposes of the present invention, the Upilex VT may be laminated to a stainless steel backing film. Another preferred polyimide for use in the present process is Upilex-50SS, from the same 10 manufacturer.

Polyphenylene polyimides have glass transition temperatures considerably higher, and water absorptions considerably lower, than those of the other polyimides previously used as transistor substrates. The commercial Upilex materials already mentioned have glass transition temperatures in excess of 400°C 15 and water absorptions not greater than about 1.4 percent. These high glass transition temperatures allow the use of higher temperatures (greater than about 300°C, and preferably greater than about 400°C) in the fabrication process than has hitherto been possible with the polyimides previously used as transistor substrates, and these higher process temperatures result in higher quality silicon layers having 20 higher mobility and low off-state current leakage. Polyphenylene polyimides also have the advantages of high dimensional stability during processing and smooth surfaces, which is important for the deposition of the thin layers of material used in

the formation of thin film transistors; for example, the aforementioned Upilex-50SS has a dimensional stability of about 0.01% and an average surface roughness of about 20 to 30 nm. An additional advantage of polyphenylene polyimides is their low coefficients of thermal expansion, which are typically about $2-10 \times 10^{-6}$ °C⁻¹, in contrast to the 35×10^{-6} °C⁻¹ typical of the polyimides previously used. Since silicon has a coefficient of thermal expansion of about 3×10^{-6} °C⁻¹, the coefficient of a polyphenylene polyimide substrate is much more closely matched to a silicon layer deposited thereon, so that the silicon layer is much less prone to cracking and/or delamination.

10 The aforementioned properties of polyphenylene polyimide substrates render the present process well adapted for use in a roll-to-roll process, in which deposition of the semiconductor material is effected on a continuous web of the polyimide substrate.

15 As already mentioned, the polyphenylene polyimide substrate used in the present process may or may not have a metal backing layer on its surface opposite to that on which the semiconductor material is to be deposited. Such a metal backing layer is useful in enhancing the mechanical integrity of the film during the transistor fabrication process, thus avoiding, for example, any tendency for the polyimide film to stretch or otherwise distort during handling, and thus reducing distortion of the substrate during formation of the transistors thereon. In addition, a metal backing layer can act as a light barrier to decrease any unwanted photo-effects in the semiconductor material (for example, photogenerated current in an amorphous silicon film) caused by light incident on the rear surface of the polyimide film. The metal backing layer need not be continuous; this layer may 20 have apertures extending through it to reduce its stiffness and thus give the metal-backed substrate more flexibility. If such apertures are to be provided, for obvious reasons it is desirable that they be formed in a regular pattern, and accordingly some or all of the apertures may be used for mechanical registration of the substrate with apparatus used in the fabrication process. Indeed, in some cases, a 25 patterned metal backing layer might be used as a shadow mask for exposure of

photoresist in a patterning step during formation of the transistors on the substrate. Alternatively or in addition, it may be advantageous to incorporate a dye into the polyimide itself to refuse or eliminate such undesirable photo-effects.

As in certain prior art processes, it may be desirable to deposit a 5 passivating layer of silica, aluminum nitride, silicon nitride or other material on the substrate prior to the deposition of the transistors on this substrate. Typically, such a passivating layer will have a thickness in the range of about 20 to about 100 nm. Passivation is useful not only for increasing the surface resistance of the polyimide 10 surface, and thus for increasing electrical insulation between adjacent conductors, but also for increasing the dimensional stability of the substrate by preventing the substrate absorbing water during processing, and for the latter purpose it is desirable to place the passivating layer on both surfaces of the substrate. It is also desirable to heat treat ("bake") the substrate to remove water from the substrate prior to the deposition of the passivating layer; such baking will generally be 15 carried out at a temperature of at least about 150°C for a period of at least about 1 minute, and preferably for about 3 minutes.

It may also be advantageous to post-bake the passivated substrate. According to a paper by Philips Research Laboratories entitled "AMLCDs and 20 Electronics on Polymer Substrates" (Euro Display 1996), the shrinkage rate of a free-standing polyimide film can be reduced by two orders of magnitude after 10 hours of heating at 275°C, and by 2.4 orders of magnitude after 100 hours at the same temperature. In one specific experiment described in this paper, after 100 baking at 275°C, a polyimide film (brand not specified) shrank at 3 ppm hr⁻¹. Accordingly, if such post-baking of the passivated substrate is desired, it should be 25 carried out at a temperature of at least 250°C for a period of at least 5 hours. It has not been determined experimentally whether these results apply to the substrate in the form of a tensioned roll, nor has it been determined experimentally whether the reduction in shrinkage still applies after the pre-baked substrate is cooled, unrolled, exposed to the processing necessary to form transistors thereon, re-rolled under

tension and reheated several days later, as is necessary for formation of transistors on the substrate in a roll-to-roll process. Alternatively, the substrate could be pre-baked in a conveyor oven immediately before deposition of the layers required to form the transistor.

5 The surface electrical resistivity of polyphenylene polyimides is, however, so high (typically $> 10^{16} \Omega$) that in many cases it may be possible to obtain adequate electrical insulation between adjacent conductors without such a passivating layer. If the passivating layer is omitted, it is still advantageous to bake the substrate before deposition of the semiconductor layer thereon in order to drive 10 off water and any other volatile materials absorbed on the polyimide, thus reducing swelling of the polyimide due to water absorption and increasing the dimensional stability of the polyimide during the formation of transistors thereon. Such baking is desirably effected at a temperature greater than 250°C for a period of at least 1 hour. In one preferred embodiment described below, the substrate is heated to 15 350°C, close to its glass transition temperature, for a period of 4 hours.

20 The presently preferred embodiments of the invention described below use an inverted transistor design, in which the gate electrodes lie adjacent the substrate. To form such inverted transistors, the first step (after any passivation and/or pre-baking of the substrate in the ways already described) is the deposition 25 of a metal layer on the substrate. The preferred metal for this purpose is chromium. It is generally preferred to deposit the chromium or other metal as a continuous film, typically having a thickness in the range of 50 to 200 nm, and thereafter to pattern the metal film, typically by conventional photolithographic techniques, prior to the deposition of the semiconductor material, to form the gate electrodes and the select lines of the transistor array to be formed. The next step in the process is normally the deposition of a layer of dielectric material, for example silicon nitride; this deposition is conveniently effected by plasma enhanced chemical vapor deposition. The semiconductor material, preferably amorphous silicon, is then deposited, again conveniently by plasma enhanced chemical vapor

deposition. As discussed in the aforementioned WO-A-00/67327, the amorphous silicon layer (and the associated dielectric layer) can, in an appropriate design, be left unpatterned so that the amorphous silicon layer extends continuously between pairs of adjacent transistors. Next, a layer of n-type silicon is deposited over the 5 amorphous silicon, again conveniently by plasma enhanced chemical vapor deposition. Finally, normally after a cleaning step to remove residues from the chemical vapor deposition processes, a metal layer, for example an aluminum layer, is deposited over the n-type silicon layer, this metal layer conveniently being deposited by thermal evaporation. The metal layer can then be patterned to form 10 source and drain electrodes by conventional photolithographic techniques, and the patterned metal layer used as an etch mask for a reactive ion etch of the n-type silicon layer; etching with a carbon tetrafluoride/oxygen mixture has been found satisfactory.

Preferred embodiments of the invention will now be described in 15 more detail, though by way of illustration only, with reference to the accompanying drawing, which shows a schematic cross-section through a single transistor formed on a polyphenylene polyimide substrate by the process of the present invention.

The accompanying drawing shows a single transistor of a transistor 20 array (generally designated 10) formed on a polyphenylene polyimide substrate 12. This substrate 12 is shown in the drawing provided with a stainless steel metal backing layer 14 through which extend regularly-spaced apertures 16, only one of which is visible in the drawing. As already mentioned, the presence of the metal backing layer 14 is optional in the process of the present invention, although such a 25 metal backing layer does provide additional mechanical integrity to the substrate and may thus facilitate handling of the substrate, especially when the invention is to be carried out on roll-to-roll coating apparatus.

On the upper surface of the substrate 12 (as shown in the drawing), 30 there is deposited a passivating layer 18 formed of silica or silicon nitride. As previously mentioned, the presence of such a passivating layer 18 is optional, and

in some cases the passivating layer 18 may be omitted, since the high surface resistivity of the polyphenylene polyimide provides sufficient insulation between adjacent transistors. Care should, however, be taken in eliminating the passivating layer 18 since if this layer is not present out-gassing from the polyimide substrate 12 may tend to cause delamination of various layers from this substrate.

On the upper surface of passivating layer 18, there are deposited an array of spaced metal gate electrodes 20 (only one of which is seen in the drawing), and above the electrodes 20 are deposited successively a dielectric layer 22, formed of silicon nitride, and a layer 24 of amorphous silicon. As discussed in the aforementioned WO-A-00/67327, the dielectric layer 22 and the amorphous silicon layer 24 can be left unpatterned, and avoiding the need to pattern these layers substantially reduces the cost of the transistor array. Finally, the transistor array comprises a layer 26 of n-type silicon and a metal electrode layer 28; both of these layers are patterned using any conventional process to provide the source and drain electrodes of the transistors.

A second preferred embodiment of the invention is generally similar to that described above, but used a polyimide substrate without a metal backing or passivating layer. In this second preferred embodiment, the aforementioned Upilex-50SS was first baked for 4 hours at 350°C to remove water and any other solvents present. A layer of chrome 100 nm. thick was deposited upon the baked substrate by thermal evaporation and photolithographically patterned to form the gate electrodes and select lines of the final transistor array. Next, a 320 nm. layer of silicon nitride dielectric was deposited on the substrate by plasma enhanced chemical vapor deposition (PECVD) using a silane/ammonia mixture; during this deposition, the substrate reached its maximum processing temperature of 350°C. A 160 nm layer of amorphous silicon semiconductor material was then deposited by PECVD from pure silane, followed by deposition of a 40 nm layer of n-type amorphous silicon by PECVD from a silane/phosphine mixture.

Following these PECVD steps, a layer of aluminum was deposited on the substrate and patterned photolithographically to form the source and drain

5 electrodes of the transistor array. The substrate was then subjected to a reactive ion etch using a carbon tetrafluoride/oxygen mixture to pattern the n-type silicon layer using the patterned aluminum layer as an etch mask; for the reasons already explained, the amorphous silicon and silicon nitride layers were not patterned during this step. Finally, a low resolution patterning step was used to pattern the amorphous silicon and silicon nitride layers to enable electrical contact to be made with the select bond line sites.

10 The thin film transistor array thus fabricated can be used directly in the manufacturer of an electrophoretic display, or other types of display, without further processing. For example, the thin film transistor array shown in the drawing could be incorporated into an electrophoretic display by the process described in WO-A-00/36465; the entire disclosure of this co-pending application is herein incorporated by reference. In some cases, it is desirable to provide a barrier layer covering the thin film transistors to protect the transistors against the 15 effects of solvents or other materials which may tend to diffuse out of the electrophoretic display.

20 The thin film transistor arrays produced by the process of the present invention are especially intended for use in electrophoretic displays, especially encapsulated electrophoretic displays such as those described in U.S. Patents Nos. 5,930,026; 5,961,804; 6,017,584; 6,067,185; 6,118,426; 6,120,588; 6,120,839; 6,124,851; 6,130,773; 6,130,774; and 6,172,798, and in International Applications Publication Nos. WO 97/04398; WO 98/03896; WO 98/19208; WO 98/41898; WO 98/41899; WO 99/10769; WO 99/10768; WO 99/10767; WO 99/53373; WO 99/56171; WO 99/59101; WO 99/47970; WO 00/03349; WO 25 00/03291; WO 99/67678; WO 00/05704; WO 99/53371; WO 00/20921; WO 00/20922; WO 00/20923; WO 00/26761; WO 00/36465; WO 00/38000; WO 00/38001; WO 00/36560; WO 00/20922; WO 00/36666; WO 00/59625; WO 00/67110; WO 00/67327 and WO 01/02899. The entire disclosures of all these patents and published applications are herein incorporated by reference.

Numerous changes and modifications can be made in the preferred embodiments of the present process already described without departing from the spirit and skill of the invention. For example, the present invention is not restricted to the fabrication of bottom gate transistors such as that shown in the accompanying drawings, the court also be used in the fabrication of top gate transistors, in which the source and drain electrodes are first fabricated on the substrate (with or without a passivating layer), then an amorphous silicon layer and a dielectric layer are formed on top of the electrodes, and finally the gate electrodes are formed as the top layer of the structure. Accordingly, the foregoing description is to be construed in an illustrative and not in a limitative sense.

From the foregoing, it will be seen that the process of the present invention provides a process for forming transistors on a flexible substrate which permits the use of higher processing temperatures than prior art processes, and which can thus produce semiconductor layers of higher quality than prior art processes. The substrate used in the present process has a coefficient of thermal expansion which closely matches that of most semiconductor layers, so reducing the risk of cracking and/or delamination of the semiconductor layer due to differences in thermal expansion between this layer and the substrate. The present invention provides a process which is well-adapted to roll-to-roll operation, and thus the present process is very suitable for the fabrication of large area transistor arrays on flexible substrates.

CLAIMS

1 1. A process for forming at least one transistor (10) on a
2 substrate (12), which process comprises depositing on the substrate (12) at least
3 one layer of semiconductor material (24, 26), characterized in that the substrate
4 (12) comprises a polyphenylene polyimide.

1 2. A process according to claim 1 characterized in that the
2 polyphenylene polyimide is a derivative of biphenyl-3,3',4,4'-tetracarboxylic acid.

1 3. A process according to claim 2 characterized in that the
2 polyimide is a derivative of biphenyl-3,3',4,4'-tetracarboxylic acid and an α,ω -
3 alkanediamine.

1 4. A process according to any one of the preceding claims
2 characterized in that a passivating layer (18) is deposited on one or both surfaces of
3 the substrate (12) before the semiconductor material (24, 26) is deposited thereon.

1 5. A process according to claim 4 characterized in that the
2 passivating layer (18) comprises silicon dioxide or aluminum nitride, and/or has a
3 thickness in the range of 20 to 100 nm.

1 6. A process according to claim 4 or 5 characterized in that the
2 substrate (12) is heated to a temperature greater than 150°C for a period of at least
3 1 minute before deposition of the passivating layer (18).

1 7. A process according to any one of claims 4 to 6
2 characterized in that the substrate (12) is heated to a temperature greater than
3 250°C for a period of at least 5 hours after deposition of the passivating layer (18).

1 8. A process according to any one of the preceding claims
2 characterized in that the substrate (12) is heated to a temperature greater than
3 250°C for a period of at least 1 hour before deposition of the semiconductor
4 material (24, 26).

1 9. A process according to any one of the preceding claims
2 characterized in that the substrate (12) comprises a metal layer (14) on the side
3 thereof remote from the semiconductor material (24, 26).

1 10. A process according to claim 9 characterized in that the
2 metal layer (14) has apertures (16) extending therethrough.

1 11. A process according to any one of the preceding claims
2 characterized in that the deposition of the semiconductor material (24) is effected
3 at a temperature in excess of 300°C.

1 12. A process according to any one of the preceding claims
2 characterized in that the semiconductor material (24) comprises amorphous silicon.

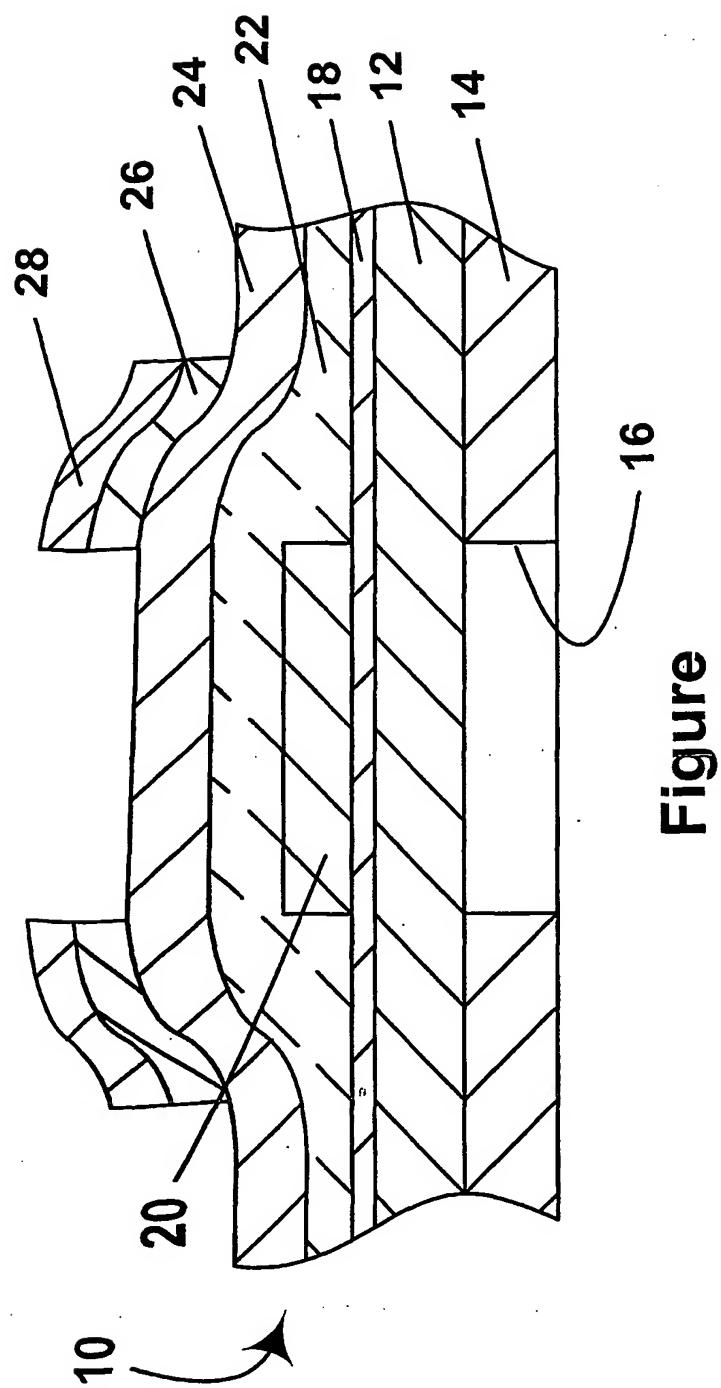
1 13. A process according to claim 12 characterized in that the
2 amorphous silicon is not patterned so that it extends continuously between at least
3 some pairs of adjacent transistors.

1 14. A process according to any one of the preceding claims
2 characterized in that deposition of the semiconductor material (24, 26) is effected
3 on a continuous web of substrate (12).

1 15. A substrate (12) comprising a polyphenylene polyimide, the
2 substrate bearing at least one transistor (10).

3 16. A substrate according to claim 15 characterized by any one
4 or more of the features defined in any of claims 2 to 14.

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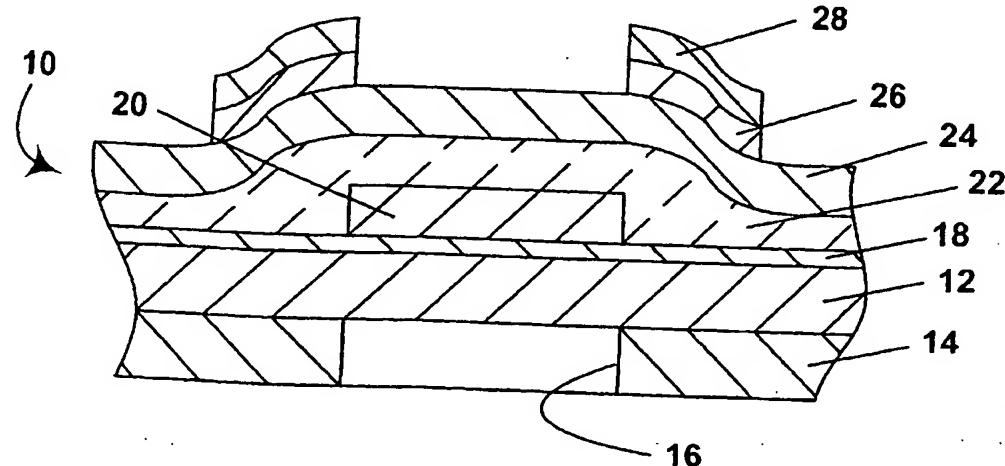
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(54) Title: PROCESS FOR FABRICATING THIN FILM TRANSISTORS



WO 01/80287 A3

(57) Abstract: Transistors are formed by depositing at least one layer of semiconductor material on a substrate comprising a polyphenylene polyimide. The substrate permits the use of processing temperatures in excess of 300 °C during the processes used to form the transistor, thus allowing the formation of high quality silicon semiconductor layers. The substrate also has a low coefficient of thermal expansion, which closely matches that of silicon, thus reducing any tendency for a silicon layer to crack or delaminate.

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L29/786

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 013 335 A (IWAGOE HIROKO ET AL) 11 January 2000 (2000-01-11) column 1, line 40 -column 2, line 16 column 13, line 5 - line 23	1,15
X	EP 0 811 648 A (UNITIKA LTD) 10 December 1997 (1997-12-10) page 2, column 1, line 10 - line 44 page 10, line 49 - line 50	1,15
X	EP 0 345 064 A (SHARP KK) 6 December 1989 (1989-12-06) page 2, line 3 -page 4, line 18	1,15
X	EP 0 336 536 A (HITACHI CHEMICAL CO LTD) 11 October 1989 (1989-10-11) page 12, line 17 - line 30; claim 2 page 28, line 6 - line 8	1,15
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Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

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Juhl, A

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
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Information on patent family members

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<p>(71) Applicant: E-INK CORPORATION [US/US]; 45 Spinelli Place, Cambridge, MA 02138 (US).</p> <p>(72) Inventors: COMISKEY, Barrett; 346 Putman Avenue, Cambridge, MA 02139 (US). ALBERT, Jonathan, D.; 347 Putman Avenue, Cambridge, MA 02139 (US). JACOBSON, Joseph, M.; 223 Grant Avenue, Newton Centre, MA 02159 (US). ZHANG, Libing; 1025 Hancock Street 13M, Quincy, MA 02169 (US). LOXLEY, Andrew; 20 Waldo Avenue #2, Somerville, MA 02143 (US). FEENEY, Robert; 20 Foxwell Lane, Scituate, MA 02066 (US). DRZAIC, Paul; 6234 Lexington Ridge Drive, Lexington, MA 02421 (US).</p> <p>(74) Agent: LANZA, John, D.; Testa, Hurwitz & Thibeault, LLP, High Street Tower, 125 High Street, Boston, MA 02110 (US).</p> <p>(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).</p>																																																																						
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<p>(54) Title: APPLICATIONS FOR ENCAPSULATED ELECTROPHORETIC DISPLAYS</p> <p>(57) Abstract</p> <p>A process for creating an electronically addressable display includes multiple printing operations, similar to a multi-color process in conventional screen printing. In some of the process steps, electrically non-active inks are printed onto areas of the receiving substrate, and in other steps, electrically active inks are printed onto different areas of the substrate. The printed display can be used in a variety of applications. This display can be used as an indicator by changing state of the display after a certain time has elapsed, or when a certain pressure, thermal, radiative, moisture, acoustic, inclination, pH, or other threshold is passed. In one embodiment, the display is incorporated into a battery indicator. A sticker display is described. The sticker is adhesive backed and may then be applied to a surface to create a functional information display unit. This invention also features a display that is both powered and controlled using radio frequencies. It describes a complete system for controlling, addressing, and powering a display. The system includes an antenna or antennae, passive charging circuitry, and active control system, a display, and an energy storage unit. There is also a separate transmitter that provides the remote power for the display. The system is meant to be used anywhere it is useful to provide intermittent updates of information such as in a store, on a highway, or in an airport. A tile-based display allowing a modular system for large area display is created using a printable display material.</p>																																																																						

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APPLICATIONS FOR ENCAPSULATED ELECTROPHORETIC DISPLAYS**Field of the Invention**

The present invention relates to display applications, and in particular, to flexible displays.

Cross-Reference to Related Applications

This application is a continuation-in-part of U.S.S.N. 08/504,896 filed July 20, 1995, 5 U.S.S.N. 08/983,404 filed July 19, 1997, and U.S.S.N. 08/935,800 filed September 23, 1997, the contents of all of which are incorporated herein by reference. This application claims priority to U.S.S.N. 60/057,133 filed August 28, 1997, U.S.S.N. 60/057,716, filed August 28, 1997, U.S.S.N. 60/057,122, filed August 28, 1997, U.S.S.N. 60/057,798, filed August 28, 1997, U.S.S.N. 60/057,799 filed August 28, 1997, U.S.S.N. 60/057,163 filed August 28, 1997, 10 U.S.S.N. 60/057,118, filed August 28, 1997, U.S.S.N. 60/059,358, filed September 19, 1997, U.S.S.N. 60/059,543 filed September 19, 1997, U.S.S.N. 60/065,529, filed November 11, 1997, U.S.S.N. 60/065,630 filed November 18, 1997, U.S.S.N. 60/065,605 filed November 18, 1997, U.S.S.N. 60/066,147, filed November 19, 1997, U.S.S.N. 60/066,245, filed November 20, 1997, U.S.S.N. 60/066,246, filed November 20, 1997, U.S.S.N. 60/066,115 filed November 21, 1997, 15 U.S.S.N. 60/066,334 filed November 21, 1997, U.S.S.N. 60/066,418 filed November 24, 1997, U.S.S.N. 60/070,940 filed January 9, 1998, U.S.S.N. 60/071,371 filed January 15, 1998, U.S.S.N. 60/072,390 filed January 9, 1998, U.S.S.N. 60/070,939 filed January 9, 1998, U.S.S.N. 60/070,935 filed January 9, 1998, U.S.S.N. 60/074,454, filed February 12, 1998, U.S.S.N. 60/076,955 filed March 5, 1998, U.S.S.N. 60/076,959 filed March 5, 1998, U.S.S.N. 60/076,957 20 filed March 5, 1998, U.S.S.N. 60/076,956 filed March 5, 1998, U.S.S.N. 60/076,978 filed March 5, 1998, U.S.S.N. 60/078,363 filed March 18, 1998, U.S.S.N. 60/081,374 filed April 10, 1998, U.S.S.N. 60/081,362 filed April 10, 1998, U.S.S.N. 60/083,252 filed April 27, 1998, U.S.S.N. 60/085,096 filed May 12, 1998, U.S.S.N. 60/090,223 filed June 22, 1998, U.S.S.N. 60/090,222 filed June 22, 1998, U.S.S.N. 60/090,232 filed June 22, 1998, U.S.S.N. 60/092,046 25 filed July 8, 1998, U.S.S.N. 60/092,050 filed July 8, 1998, U.S.S.N. 60/092,742 filed July 14, 1998, and U.S.S.N. 60/093,689 filed July 22, 1998, the contents of all of which are incorporated herein by reference.

Background of the Invention

Many applications can benefit from inclusion of a display. For example, projection devices, sketching apparatuses, telephones, pocketbooks, and battery indicators are only a few applications that display transient information. To date, widespread incorporation of displays has 5 been hindered because such applications generally require flexible displays that consume very little power.

Despite much effort directed to developing highly-flexible, reflective display media, there are relatively few examples of displays formed on semi-flexible substrates, and these examples have found only moderate success. For example, plastic-based liquid crystal displays, including 10 twisted nematic (TN), supertwisted nematic (STN), polymer dispersed liquid crystal (PDLC), and bistable cholesteric liquid crystals have been developed. Nevertheless, problems remain with liquid crystal alignment in TN and STN displays, cholesteric displays are sensitive to changes in their cell gap, and local stress can cause changes in the scattering or absorbance of PDLC and cholesteric films. As such, only moderate flexibility can be achieved with these displays.

15 Emissive electroluminescent films and organic light emitting diode films can be deposited on flexible substrates to create flexible displays. However, these devices require continuous power consumption for operation, and thus are not practical for many applications.

Another problem with developing highly flexible displays is the lack of an appropriate 20 conductor for addressing the display elements. Typically, an indium tin oxide (ITO) layer vacuum sputtered onto a plastic substrate is used as a top conductor for displays. An ITO layer, however, can be damaged when the display is flexed. If the local curvature of the plastic substrate becomes too great, the ITO layer tends to crack, damaging the display.

Summary of the Invention

An object of the invention is to provide a highly-flexible, reflective display which can be 25 manufactured easily, consumes little (or no in the case of bistable displays) power, and can, therefore, be incorporated into a variety of applications. The invention features a printable display comprising an encapsulated electrophoretic display medium. The resulting display is flexible. Since the display media can be printed, the display itself can be made inexpensively.

An encapsulated electrophoretic display can be constructed so that the optical state of the 30 display is stable for some length of time. When the display has two states which are stable in this manner, the display is said to be bistable. If more than two states of the display are stable, then

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the display can be said to be multistable. For the purpose of this invention, the term bistable will be used to indicate a display in which any optical state remains fixed once the addressing voltage is removed. The definition of a bistable state depends on the application for the display. A slowly-decaying optical state can be effectively bistable if the optical state is substantially 5 unchanged over the required viewing time. For example, in a display which is updated every few minutes, a display image which is stable for hours or days is effectively bistable for that application. In this invention, the term bistable also indicates a display with an optical state sufficiently long-lived as to be effectively bistable for the application in mind. Alternatively, it is possible to construct encapsulated electrophoretic displays in which the image decays quickly 10 once the addressing voltage to the display is removed (i.e., the display is not bistable or multistable). As will be described, in some applications it is advantageous to use an encapsulated electrophoretic display which is not bistable. Whether or not an encapsulated electrophoretic display is bistable, and its degree of bistability, can be controlled through appropriate chemical modification of the electrophoretic particles, the suspending fluid, the capsule, and binder 15 materials.

An encapsulated electrophoretic display may take many forms. The display may comprise capsules dispersed in a binder. The capsules may be of any size or shape. The capsules may, for example, be spherical and may have diameters in the millimeter range or the micron range, but is preferably from ten to a few hundred microns. The capsules may be formed by an encapsulation 20 technique, as described below. Particles may be encapsulated in the capsules. The particles may be two or more different types of particles. The particles may be colored, luminescent, light-absorbing or transparent, for example. The particles may include neat pigments, dyed (laked) pigments or pigment/polymer composites, for example. The display may further comprise a suspending fluid in which the particles are dispersed.

25 The successful construction of an encapsulated electrophoretic display requires the proper interaction of several different types of materials and processes, such as a polymeric binder and, optionally, a capsule membrane. These materials must be chemically compatible with the electrophoretic particles and fluid, as well as with each other. The capsule materials may engage in useful surface interactions with the electrophoretic particles, or may act as a chemical or 30 physical boundary between the fluid and the binder.

In some cases, the encapsulation step of the process is not necessary, and the electrophoretic fluid may be directly dispersed or emulsified into the binder (or a precursor to the binder materials) and an effective "polymer-dispersed electrophoretic display" constructed. In such displays, voids created in the binder may be referred to as capsules or microcapsules even though no capsule membrane is present. The binder dispersed electrophoretic display may be of the emulsion or phase separation type.

Throughout the specification, reference will be made to printing or printed. As used throughout the specification, printing is intended to include all forms of printing and coating, including: premetered coatings such as patch die coating, slot or extrusion coating, slide or cascade coating, and curtain coating; roll coating such as knife over roll coating, forward and reverse roll coating; gravure coating; dip coating; spray coating; meniscus coating; spin coating; brush coating; air knife coating; silk screen printing processes; electrostatic printing processes; thermal printing processes; and other similar techniques. A "printed element" refers to an element formed using any one of the above techniques.

In one aspect, the invention features an indicator. The indicator includes a substrate, a transducer, and an electrically addressable display printed on the substrate in electrical communication with the transducer. The transducer is, in some embodiments, printed on the substrate and, in other embodiments, is conventionally disposed on the substrate. The display shows a change in optical state in response to a signal from the transducer. In one embodiment, the indicator is a battery indicator. The battery indicator is in electrical communication with a battery and comprises an electrically addressable display printed on the battery. The optical state shows a first value in response to a voltage of the battery. In one detailed embodiment, the battery indicator includes an electrophoretic display comprising a microencapsulated display media, a first electrode and a second electrode disposed adjacent the electrophoretic display, a nonlinear element, a voltage divider, and a resistor. The first and second electrodes apply an electric field to the electrophoretic display media. The nonlinear element is in electrical communication with a battery and the first electrode. The nonlinear element conducts a battery voltage to the first electrode when the battery voltage exceeds a predetermined threshold. The voltage divider is in electrical communication with the battery and the second electrode. The voltage divider provides a voltage to the second electrode that is less than the battery voltage. The resistor is in electrical communication with the nonlinear element and the voltage divider.

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In another aspect, the invention features a sticker display. The electrically active sticker display includes an encapsulated display media and an adhesive layer disposed on the first surface of the display media. In some cases, the encapsulated electrophoretic display may be itself sufficiently adhesive to function as a sticker without additional adhesive layers. The display media 5 comprises an optoelectrically active material. In one embodiment, a transparent layer including an electrode is disposed adjacent a surface of the display media. In another embodiment, the sticker display further includes a via which extends from the transparent layer to the adhesive layer.

In still another aspect, the invention features a method of printing an electrically active display. The methods comprises the steps of: (a) providing a film having a clear electrode 10 structure disposed on a first surface of the film; (b) printing a display media on the first surface of the film; and (c) printing or laminating a second electrode covering at least a portion of the display media. The display media comprises an encapsulated optoelectrically active material dispersed in a binder

In still another aspect, the invention features a radio-controlled display. The radio 15 controlled display includes an electrically active display having an encapsulated display media, a receiver, and a decoder in electrical communication with the receiver. The display is responsive to the output of the decoder. In one embodiment, the display further includes a power source in connection with the display. In another embodiment, the display further includes a plurality of row and column drivers disposed on the substrate for addressing the display. In still another embodiment, the display further includes an antenna in communication with a control circuit.

In still another aspect, the invention features a process for creating an electrically addressable display. The method comprises the steps of (a) providing a substrate; and (b) printing an electrically active ink comprising at least one microcapsule dispersed in a binder onto a first area of a receiving substrate. Optical qualities of the electrically active ink are modulated 25 responsive to broadcast signals.

In still another aspect, the invention features a process for printing an electrically addressable display. The method comprises the steps of: (a) providing a substrate; and (b) printing an electrically active ink comprising at least one microcapsule dispersed in a binder onto a first area of the receiving substrate.

30 In still another aspect, the invention features an electrically active display tile. The tile includes a substrate, an electrically addressable display disposed on the substrate, a controller

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disposed on the substrate in electrical communication with the display, and a connector disposed on the substrate for connecting the display tile to another display tile. The display comprises a encapsulated display medium. In one embodiment, the display tile further includes a receiver for receiving radio signals or other electromagnetic radiation, and the controller changes the display 5 in response to the received radio signals. In another embodiment, the display tile further includes a memory element storing data, and the controller changes the display responsive to data stored in the memory element.

In still another aspect the invention features a wearable display. A wearable display includes an article of clothing including an electrically addressable display incorporated into the 10 wearable item and a controller in electrical communication with the display. The display comprises an encapsulated display media. In one embodiment, the controller is incorporated into the wearable item. In another embodiment, the wearable item comprises a fashion accessory. In still another embodiment, the wearable item includes an interface for receiving information from another device that can be displayed by the wearable item, such as a temperature monitor or 15 position-sensing device.

Brief Description of the Drawings

The invention is pointed with particularity in the appended claims. The advantages of the invention described above, together with further advantages, may be better understood by referring to the following description taken in conjunction with the accompanying drawings. In 20 the drawings, like reference characters generally refer to the same parts throughout the different views. Also, the drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention.

FIG. 1 shows an exploded view of one embodiment of a printed flexible electrophoretic display.

25 FIG. 2 shows a block diagram of an indicator prepared according to the present invention.

FIG. 3 shows a circuit diagram of an embodiment of a battery indicator.

FIG. 3A shows a voltage-current curve of a non-linear element included in a battery indicator.

FIGS. 4A-4B show various embodiments of display media that is not bistable.

30 FIGS. 5A-5F show various embodiments of a sticker display.

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FIG. 6A shows a flow chart illustrating how one embodiment of a radio-controlled display functions.

FIG. 6B shows one embodiment of a radio-controlled display.

FIG. 7 shows one embodiment of a radio paper.

5 FIGS. 8A-8D depict a tile display system.

FIG. 8E shows one embodiment of a block diagram of a tile display.

FIG. 9 shows one embodiment of a wearable display.

FIG. 10 shows a block diagram of one embodiment of network data displays.

10 Detailed Description of the Invention

According to the present invention, a substrate is provided and an electronic ink is printed onto a first area of the substrate. The present invention takes advantage of the physical properties of an electronic ink which permits a wide range of printing and coating techniques to be used in creating a display. An electronic ink is an optoelectronically active material which comprises at 15 least two phases: an electrophoretic contrast media phase and a coating/binding phase. The electrophoretic phase comprises, in some embodiments, a single species of electrophoretic particles dispersed in a clear or dyed medium, or more than one species of electrophoretic particles having distinct physical and electrical characteristics dispersed in a clear or dyed medium. The coating/binding phase includes, in one embodiment, a polymer matrix that surrounds the 20 electrophoretic phase. In this embodiment, the polymer in the polymeric binder is capable of being dried, crosslinked, or otherwise cured as in traditional inks, and therefore a printing process can be used to deposit the electronic ink onto a substrate. An electronic ink is capable of being printed by several different processes, depending on the mechanical properties of the specific ink employed. For example, the fragility or viscosity of a particular ink may result in a different 25 process selection. A very viscous ink would not be well-suited to deposition by an inkjet printing process, while a fragile ink might not be used in a knife over roll coating process.

The optical quality of an electronic ink is quite distinct from other electronic display materials. The most notable difference is that the electronic ink provides a high degree of both reflectance and contrast because it is pigment based (as are ordinary printing inks). The light 30 scattered from the electronic ink comes from a very thin layer close to the top of the viewing

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surface. In this respect it resembles a common, printed image. Thus, electronic ink is easily viewed from a wide range of viewing angles in the same manner as a printed page. Such ink approximates a Lambertian contrast curve more closely than any other electronic display material. Since electronic ink can be printed, it can be included on the same surface with any other printed material. Electronic ink can be made optically stable in all optical states, that is, the ink can be set to a persistent optical state. Fabrication of a display by printing an electronic ink is particularly useful in low power applications because of this stability.

If desired, the colors of electronically active and non-active inks may closely match and the reflectivities may be similar. Electronic inks can be printed so that no border is noticeable between active and non-active inks. This is referred to as "color matching" or "color masking". Therefore, a display comprising an electronically active portion may appear as if it is not electronically active when the display is not being addressed and may be activated by addressing the display. Electronic inks are described in more detail in co-pending United States Patent Application Serial No. 08/935,800, the contents of which are incorporated herein by reference.

Referring to FIG. 1, a display 1 is created by printing a first conductive coating 2 on a substrate 3, printing an electronic ink 4 on the first conductive coating 2, and printing a second conductive coating 6 on the electronic ink 4. Conductive coatings 2, 6 may be Indium Tin Oxide (ITO) or some other suitable conductive material. The conductive layers 2, 6 may be applied from a vaporous phase, by electrolytic reaction, or deposition from a dispersed state such as spray droplets or dispersions in liquids. Conductive coatings 2, 6 do not need to be the same conductive material. In one detailed embodiment, the substrate 3 is a polyester sheet having a thickness of about 4 mil, and the first conductive coating 2 is a transparent conductive coating such as ITO or a transparent polyaniline. The second conductive coating 6 may be an opaque conductive coating, such as a patterned graphite layer. Alternatively, the second conductive coating 6 can be polymeric. The polymer can be intrinsically conductive or can be a polymer carrier with a metal conductor such as a silver-doped polyester or a silver-doped vinyl resin. Conductive polymers suitable for use as the second electrode include, for example, polyaniline, polypyrole, polythiophene, polyphenylenevinylene, and their derivatives. These organic materials can be colloidally dispersed or dissolved in a suitable solvent before coating.

In another embodiment, a display 1 is created by printing a first conductive coating 2 on a first substrate 3, printing an electronic ink 4 on the first conductive coating 2, printing a second

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conductive coating 6 on a second substrate 3', and configuring the substrates 3, 3' such that the second conductive coating 6 is in electrical communication with the electronic ink 4.

The electronic ink 4 comprises a plurality of capsules. The capsules, for example, may have an average diameter on the order of about 100 microns. Capsules this small allow significant 5 bending of the display substrate without permanent deformation or rupture of the capsules themselves. The optical appearance of the encapsulated medium itself is more or less unaffected by the curvature of these capsules.

One of the benefits of using printing methods to fabricate displays is eliminating the need for vacuum-sputtered ITO by using coatable conductive materials. The replacement of vacuum- 10 sputtered ITO with a printed conductive coating is beneficial in several ways. The printed conductor can be coated thinly, allowing for high optical transmission and low first-surface reflection. For example, total transmission can range from about 80% to about 95%. In addition, the printed conductive coating is significantly less expensive than vacuum-sputtered ITO.

Another advantage of the encapsulated electrophoretic display medium is that relatively poor 15 conductors, for example, materials with resistivities on the order of 10^3 - 10^{12} ohms square, can be used as lead lines to address a display element.

The flexible, inexpensive display described above is useful in numerous applications. For example, these, flexible displays can be used in applications where paper is currently the display medium of choice. Alternatively, the displays can be made into disposable displays. The displays 20 can be tightly rolled or bent double. In other embodiments, the displays can be placed onto or incorporated into highly flexible plastic substrates, fabric, or paper. Since the displays can be rolled and bent without sustaining damage, they form large-area displays which are highly portable. Since these displays can be printed on plastics they can be lightweight. In addition, the printable, encapsulated electrophoretic display of the present invention can maintain the other 25 desirable features of electrophoretic displays, including high reflectance, bistability, and low power consumption.

The printable display described above can be incorporated into a variety of applications. In one embodiment, the invention features a new type of indicator that can be printed in its 30 entirety. FIG. 2 shows a block diagram of an indicator 10. The indicator 10 includes an electronically addressable display 12 which is capable of changing between at least two states, and a transducer 14 which is capable of generating an electrical event to trigger the change in the state

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of the display 12. The electronically addressable display 12 and the transducer 14 can both be printed onto a substrate 16. FIG. 2 depicts an embodiment in which the indicator 10 further includes a printed battery 18 to power the transducer 14 and the display 12. In one embodiment, the transducer 14 need not be printed. In this embodiment, a conventional transducer 14 may be 5 placed on the substrate 16. The display media 12 is printed as described above. The media 12 may be printed before or after the transducer it is placed, provided that the display media 12 is ultimately in electrical communication with the transducer 14.

In another embodiment, the battery 18 is a conventional battery, the voltage of which is measured and displayed on the display 12. In one detailed embodiment, a battery indicator 10 includes a printed display directly connected to a battery. The battery continuously addresses the display, but as the battery discharges over time, it eventually reaches a point where it is incapable of addressing the display. By varying the characteristics of the transducer, for example the number of amp-hours contained by the battery, the battery indicator can function as a "timer," so that the display shows a message such as "*expired*" after passage of a certain electrical charge.

15 FIG. 3 shows a circuit diagram of a battery indicator 20. The battery indicator 20 includes a display 22 comprising a display media 24, a first electrode 26 and a second electrode 27 disposed adjacent the display media 24, a nonlinear element 28 in electrical communication with the first electrode 26 and a battery 30, a voltage divider 32 in electrical communication with the battery 30 and the second electrode 27, and a resistor 34 in communication with the nonlinear 20 element 28 and the voltage divider 32.

The battery 30 can be of any type. The battery 30 initially has a maximum voltage. The voltage divider 32 establishes a voltage potential that is some fraction of the battery cell voltage at the second electrode 27. In the embodiment shown in FIG. 2, the voltage divider 32 includes high impedance resistors 36 and 38. The voltage divider 32, for example, can have two 5 megaohm 25 resistors to apply a voltage potential that is equal to one-half of the battery cell voltage to the second electrode 27. Alternatively, the battery indicator can have a sliding voltage divider. A sliding voltage divider may be provided as a potentiometer using a non-linear element to control the voltage applied to the display 24.

30 The nonlinear element 28 conducts voltage equal to the battery cell voltage to the first electrode 26 when the battery cell voltage exceeds the predetermined threshold voltage. Examples of suitable non-linear elements include a transistor, zener diode, varistor, metal-

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insulator-metal structure, organic semiconductors and devices based on materials like pentacene or regio-regular thiophene, or any other nonlinear devices known to those skilled in the art.

FIG. 3A shows an exemplary current-voltage characteristic of a nonlinear element 28 which can be used in the battery indicator 20. The threshold voltage is adjustable through manufacturing,

5 and the threshold is selected to be a voltage at which the battery 30 is still useable. As long as the battery 30 is above the threshold, the junction breaks down and the first electrode 26 is set at the battery cell voltage. A useful battery indicator should have a very low leakage current (e.g., much less than 1 microampere (μ A)) and should allow at least about a hundred times as much current to flow when it is on than when it is off. The threshold voltage at which the state of the display

10 changes depends on the battery with which the indicator is designed to work. A threshold voltage of about 8 volts (V) is typical for a 9 V alkaline. For example at 9 V, the device should pass 1 μ A, at 8 V the device should pass 100 nanoamperes (nA), and at 7 V the device should pass 10 nA.

The voltage from the battery 30 which passes through the nonlinear element 28 and is applied to the first electrode 26, combined with the voltage from the battery 30 which passes

15 through the voltage divider 32 and is applied to the second electrode 27, to provide an electric field across the display media 24 sufficient to activate the display 22. At least one of the first and second electrodes 26, 27 comprises a clear conductive material to permit viewing of the display 22. Alternatively, both electrodes may be placed on one side of the display media 24, eliminating the need for a clear electrode. Once the battery voltage 30 drops below the threshold, however,

20 the potential at the first electrode 26 is drained through the resistor 34. Draining of the potential at the first electrode 26 changes the electric field across the display media 24 such that an electric field of opposite polarity is applied to the display media 24 and the appearance of the display 22 changes.

The resistor 34, for example, can be a 10 megaohm resistor for a typical 9 V battery. A typical 9 V battery has a 400 milliampere hour (mAh) rating. Over a 5 year period, there are 43,800 hours (5 years x 365 days/year x 24 hours/day = 43800 hours). Thus, the indicator 20 must draw less than 1 (400mAh/43800h) in order for the battery 30 to have a suitable shelf life.

Ideally, the indicator 20 should draw less than 1 μ A. In order to achieve such a low current draw, the impedance of the indicator 20 must be in the order of 10 megaohms.

30 As noted above, a circuit permanently connected to a battery should consume very little power. A number of display materials are suitable for such an application. However, some of

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these display materials, such as a liquid crystal display, require a more complex cell in their manufacture. In the present invention, encapsulated electrophoretic displays and encapsulated twisting ball displays are preferred as the display media 24 because of their low power draw, printability, and good contrast. Encapsulated electrophoretic display media, for example, includes 5 a mixture of electrophoretic particles and a dye, or electrophoretic particles comprising multiple optical properties.

In one embodiment in which the battery indicator 20 operates by applying an electric field of one polarity while the battery is good, and then switching to the opposite polarity when the battery goes bad. Thus, the display media is not required to be bistable.

10 Referring to FIG. 4A, a display media 180 that is not bistable comprises at least one capsule 185, each filled with electrophoretic particles 210 and a fluid 220. Such media is useful in battery applications because the media will exhibit one contrast state when the display is addressed by the battery and a second contrast state when not addressed by the battery, i.e., when the battery voltage level falls below the threshold voltage necessary to address the display. In the 15 embodiment depicted in FIG. 4A, electrophoretic particles 210 have polymer chain branches 200 which cause one particle 210 to repel another particle 210. In one detailed embodiment, the fluid 220 is dyed to provide a color contrast with the particles 210. When the display media is addressed, the particles 210 migrate towards an electrode with an opposite charge, thereby displaying the color of the particles 210. Once the display media is no longer being addressed, the 20 particles 210 repel each other and redistribute within the fluid 220, thereby displaying the color of the fluid 220. This encapsulated display media 180 can be printed onto a substrate to form a display. Alternatively, an electrophoretic display that is not bistable can be formed by providing a standard display cell filled with electrophoretic media that is not bistable.

25 Referring to FIG. 4B, another display media 290 that is also not bistable includes at least one microcapsule or cell 292, filled with a plurality of metal sol 296 and a clear fluid 294. Metal sol 296 are particles which are smaller than a wavelength of light. In one detailed embodiment, the metal sol 296 comprises gold sol. When an electric field is applied across the microcapsule or cell 292, sol particles 296 agglomerate and scatter light. When the applied electric field is reduced to below a certain level, Brownian motion causes the sol particles 296 to redistribute, and 30 the display media 290 appears clear from the clear fluid 294.

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In another detailed embodiment, multiple indicators mapped to different voltage thresholds are used to create a battery indicator. An important element in this embodiment is a circuit element that provides a sharp non-linearity at a well-controlled voltage level.

In still another detailed embodiment, the battery indicator combines multiple non-linearities in order to provide a proper fit of the voltage curve for the open circuit voltage to be mapped to the closed circuit voltage. It is known that a battery with no load shows a voltage that is not the same as the loaded voltage. Therefore, non-linearity may be used to compensate for this difference. In addition, a known mapping of the closed circuit voltage to open circuit voltage may be used in the printed scale of the indicator.

10 In another detailed embodiment, the invention features a timer. A timer includes a junction formed of p-type semiconductor (e.g., boron doped) and an intrinsic or undoped semiconductor. In this device, current does not flow. However, if the intrinsic semiconductor becomes n-doped (i.e., if the semiconductor has extra electrons available from the valence shell of dopant atoms), then current could flow from the n-doped region to the p-doped region.

15 Normally, intrinsic semiconductors become n-doped if doped with phosphorous. Alternatively, the same result can be achieved by embedding or placing in close proximity to the intrinsic region a beta particle emitting substance such as tritium. Likewise, the intrinsic region of an n-doped-intrinsic junction semiconductor may be treated with an alpha particle emitter such as Helium-5 to convert it to a p-doped region. Over time, a non-conducting junction with an alpha

20 or beta particle emitter embedded in its intrinsic region transforms into a diode-type junction which passes current, thereby acting as a timer.

In another detailed embodiment, a timer employs a p-n junction semiconductor sensitive to light, such that light forces a current to flow from the n-region to the p-region. The timer can include a tritiated phosphor in a Zener diode and a display. A Zener diode is a diode designed to survive reverse breakdown. Light applied to the Zener diode through the tritiated phosphor increases the breakdown voltage of the Zener diode. When the tritiated system wears out, the Zener diode breakdown voltage decreases and voltage is applied to the display.

In another detailed embodiment, a pressure indicator includes a transducer and a display. In some embodiments, the transducer is printed. In other embodiments, the display is an encapsulated electrophoretic display. The transducer, for example, comprises a printed mechanical switch which **closes once** a certain pressure threshold is exceeded, thereby causing a

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printed display to change its state. In another example, pressure can change the electrical characteristics (e.g., the capacitance) of a circuit containing the display, thereby changing the state of the display once a threshold value has been exceeded. Alternatively, the transducer can provide power to switch the state of the display. One example of such a transducer is a
5 piezoelectric element. In other embodiments, a solar cell may provide power to the display.

In another detailed embodiment, a heat indicator includes a display and a thermally-sensitive structure capable of changing the state of the display in response to a thermal stimulus. In some embodiments the structure is printed. In other embodiments the display is an encapsulated electrophoretic display. For example, a printed bimetallic mechanical system can
10 serve as an electrical switch which changes the state of the printed display. Alternatively, a printed chemical structure which reacts to a thermal condition can be used to change the resulting electrical properties and the state of the display. Still another possibility is a transducer which provides power to switch the state of the display, for example, from an electrochemical potential. In other embodiments, a solar cell may provide power to the display.

15 In another detailed embodiment, a light indicator includes a display and a photosensitive structure capable of changing the state of the display in response to a photonic stimulus. In some embodiments the structure is printed. In other embodiments the display is an encapsulated electrophoretic display. For example, a printed solar cell array has a photovoltaic characteristic which is capable of providing a voltage to switch the state of the display in response to incident
20 photons. Other structures which are sensitive to other radiative ranges (e.g. infrared, ultraviolet, etc.) could also be printed onto a substrate with the display. In other embodiments, a solar cell may provide power to the display.

In another detailed embodiment, a moisture indicator includes a display and a moisture-sensitive structure capable of changing the state of the display in response to humidity or direct
25 aqueous contact. In some embodiments the structure is printed. In other embodiments the display is an encapsulated electrophoretic display. For example, a structure can be printed which is an open circuit until an ionic solution bridges two exposed electrical contacts, thus changing the state of the display. Alternatively, a chemical structure can be printed which, after the absorption of a certain amount of water, changes the electrical properties sufficiently to change the state of
30 the display. This transducer can provide power to switch the state of the display, for example using an accumulated electrochemical potential. Useful materials for this purpose include

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polyvinylalcohol, poly-N-vinylpyrrolidone, polyvinylpyrrolidone, derivatives of these materials, starches, and sugars. In other embodiments, a solar cell may provide power to the display.

In still another detailed embodiment, a sound indicator includes a display and an acoustically-sensitive structure capable of changing the state of the display in response to an 5 acoustical stimulus. In some embodiments the structure is printed. In other embodiments the display is an encapsulated electrophoretic display. For example, a mechanically resonating structure could be printed which changes the state of the display based on piezoelectrically generated energy, similar to a microphone. In other embodiments, a solar cell may provide power to the display.

10 In still another detailed embodiment, an angle indicator includes a display and a structure sensitive to orientation that is capable of changing the state of the display in response to a change in the orientation of the indicator. In some embodiments the structure is printed. In other embodiments the display is an encapsulated electrophoretic display. For example, a mercury switch type structure could be provided which closes two electrical contacts when a certain 15 orientation has been reached. The orientation structure can also provide power to switch the state of the display. For example, the transducer can include a mechanical structure which converts a mechanical energy involved in angular rotation into an electrical energy. In other embodiments, a solar cell may provide power to the display.

20 In still another detailed embodiment, a pH indicator includes a display and a pH-sensitive structure capable of changing the state of the display in response to a change in the pH of a solution in which the indicator is immersed. In some embodiments the structure is printed. In other embodiments the display is an encapsulated electrophoretic display. For example, a chemical cell which undergoes a chemical reaction at a certain pH level can be printed and can change the state of the display. The pH-sensitive structure can also provide power to switch the 25 state of the display. For example, an electrochemical potential can be generated by the chemical reaction. In other embodiments, a solar cell may provide power to the display.

30 In still another detailed embodiment, a chemical indicator includes a display and a chemically-sensitive structure capable of changing the state of the display in response to an external chemical interference. In some embodiments the structure is printed. In other embodiments the display is an encapsulated electrophoretic display. For example, a printed chemical sensor can be sensitive to an externally introduced agent which causes a chemical

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reaction to occur, and switches the state of the display. The chemically-sensitive structure can also provide power to switch the state of the display. For example, an electrochemical potential can be generated by the chemical reaction. In other embodiments, a solar cell may provide power to the display.

5 Additional transducers, other than those described above, that are capable of providing a signal to change the state of the display in addition to providing power to change the state of the display will be readily apparent to those of ordinary skill in the art.

10 In still another detailed embodiment, any of the above transducers can be connected to another transducer to create a multi-level transducer path which changes the state of display. For example, an indicator can include a chemically-sensitive structure, a thermally-sensitive structure, and a display, all of which may be printed on a substrate. Heat from an exothermic reaction created by the chemically-sensitive structure can be sensed by the thermally-sensitive structure, which in turn changes the state of the display and may also be used to power the display.

15 In another embodiment, an encapsulated electrophoretic display is used to create a printable, adhesive display. Referring to FIG. 5A, a printable, adhesive display 40 includes a substrate 42 coated with a conducting layer forming a top electrode 44, a display media 46 disposed adjacent the top conductor 44, and an adhesive 48 disposed adjacent the display media 40. The display media 40 comprises an optoelectrically active component 50 and a binder 52 which holds the optoelectrically active component 50 together. The substrate 42 and the top 20 electrode 44 are optically transmissive to allow the display 40 to be viewed through the electrode. The substrate 42, for example, can be formed of a polymeric material such as a polyester. The top electrode 44, for example, can be formed of an inorganic material such as ITO or a suitable polymeric material. The optoelectrically active component 50, for example, can be an encapsulated electrophoretic display material. Alternatively, the optoelectrically active 25 component 50 can be any other suitable display material such as biochromal microspheres or liquid crystals. The binder 52, for example, can be selected from polyurethanes, polyvinylalcohols, gelatins, polyacrylates, polystyrenes, polyvinylbutyrals, polyesters, epoxies, silicones, polycarbonates, their derivatives, and pressure-sensitive urethanes and adhesives.

30 In operation, the adhesive display 40 is attached to a receiving surface (not shown) by the adhesive 48. The receiving surface may include rear electrodes for addressing the optoelectrically active component 50. The rear electrodes may be electrically connected to

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drive or power circuitry for operating the display 40. In this embodiment, the display 40 is addressed in a "coupling" mode, where the top electrode 42 is "floating" and not directly tied to any specific potential.

Referring to FIG. 5B, an adhesive display 56 includes a substrate 42, a top electrode 44 disposed on the substrate 42, a display media 46 comprising an optoelectronically active component 50 and a binder 52, the display media 46 disposed adjacent the top electrode 44, and an adhesive 48 disposed adjacent display the media 46. In this embodiment, the adhesive display 56 further includes a via 60 which electrically connects the top electrode 44 to a pad 62 disposed on a rear surface of the display media 46, and a conductive adhesive 64 is disposed adjacent the pad 62. The rear electrodes are disposed on a receiving surface (not shown) to which the adhesive display 56 is applied. In this embodiment, the top electrode 44 may be directly connected to a specific potential.

Referring to FIG. 5C, an adhesive display 70 includes a substrate 42, a patterned, optically-transmissive conducting layer 72 forming a plurality of top electrodes, the layer 72 coated on the substrate 42, a display media 46 comprising an optoelectronically active component 50 and a binder 52 disposed adjacent the substrate 42, and an adhesive 48 disposed adjacent the display media 46. The adhesive display 70 further includes at least one via 60 which electrically connects at least one top electrode 72 to a pad 62 disposed on a rear surface of the display media 46. A conductive adhesive 64 may be disposed adjacent the display media in the general location of the pads 62. The rear electrodes may be disposed on a receiving surface (not shown) to which the adhesive display 70 is applied.

Referring to FIG. 5D, an adhesive display 80 includes a substrate 42, a continuous top electrode 44 disposed on the substrate 42, a display media 46 comprising an optoelectronically active component 50 and a binder 52 disposed adjacent the top electrode 44, at least one patterned rear electrode 82 disposed adjacent a rear surface of the display media 46, and conductive adhesive 64 disposed adjacent the rear electrodes 82 for adhering the display 80 to a receiving surface (not shown). In this embodiment, the receiving surface may include drive or power circuitry for operating the display 80. In this embodiment, the display 80 is addressed in a "coupling" mode where the top electrode is "floating."

Referring to FIG. 5E, an adhesive display 90 includes a substrate 42, at least one patterned top electrode 72 disposed on the substrate 42, a display media 46 comprising an

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5 optoelectronically active component 50 and a binder 52 disposed adjacent the top electrode 72, at least one patterned rear electrode 82 disposed adjacent a rear surface of the display media 46, and a dielectric layer 92 disposed adjacent the rear electrodes 82. The adhesive display 90 further includes at least one via 60 which extends from a top electrode 72 through the display media 46 and the dielectric layer 92 to at least one pad 62 disposed on a rear surface of the dielectric layer 92. The adhesive display 90 further includes at least one via 94 which extends from a rear electrode 82 through the dielectric layer 92 to at least one pad 96 disposed on a rear surface of the dielectric layer 92. Conductive adhesive 64 is disposed in the general location of the pads 62 and 96 to adhere the display 90 to a receiving surface and to provide electrical communication 10 between circuitry on the receiving surface and the electrodes 72, 82 of the display 90. The display 90 can further include a nonconductive adhesive 48 disposed adjacent the exposed dielectric layer 92 to further assist in adhering the display 90 to the receiver.

15 Referring to FIG. 5F, an adhesive display 98 includes a substrate 42, a display media 46 comprising an optoelectronically active component 50 and a binder 52 disposed adjacent the substrate 42, and an adhesive 48 disposed adjacent a rear surface of the display media 46. In this embodiment, the display 98 is addressed by rear electrodes (not shown) only. The rear electrodes are disposed on a receiving surface to which the display 98 is applied. Alternatively, the rear electrodes may be disposed on a rear surface of the display 98 as shown in FIGS. 5D and 5E.

20 In the embodiments described above, a stylus may be provided that acts as the top electrode to address the adhesive display 40. In this embodiment, the stylus may be scanned over the entire display to address it. Alternatively, the stylus may be used as a writing utensil, addressing only specific portions of the display over which it is passed.

25 In another embodiment, an encapsulated, electrophoretic display is used to form a radio-controlled display system. Referring to FIG. 6A, the radio-controlled display system 300 includes a remote transmitter 370, a receiver 301, a controller 340, and a display unit 350. In one embodiment, the receiver 301 includes an antenna 302. In one more particular embodiment, the receiver 301 is in electrical communication with a passive rectifier 310 which transforms and rectifies energy received by the antenna 302. The antenna 302 can be a monopole antenna, a dipole antenna, a planar array, a coil or any other antenna structure known in the art of radio 30 reception.

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As shown in FIG. 6B, the antenna 302 may be disposed in a surrounding relation to the display 350, allowing power to be received from relatively low-power signals. For example, an antenna having a cross-sectional area of .1 square meters that receives a 10,000 watt signal at a distance of 5,000 m can receive 3 microwatts of power. In other embodiments the display 350 is 5 powered by a solar cell (not shown).

In one embodiment, the antenna 302 includes a plurality of antennas to improve the reception level. The display system 300 further includes an energy storage device 320 in communication with the passive rectifier 310. The energy storage device 320 can be a capacitor, a battery, or any other electrical or non-electrical energy storage device known in the art of 10 energy storage. In the case of a non-electrical energy storage, a transducer can be used to transfer electrical energy into another form of energy.

When the energy level in the energy storage device 320 reaches a certain level as detected by an energy level detector 330, the controller 340 is activated and the display can be updated. The controller 340 decodes the radio signals received by the antenna 302 and updates the display 15 350 based on the information received by the antenna 302. Each display 350 can have a unique identification code 360 that may be stored as dip switch settings or as programmed data in a semiconductor device such as a PROM or Flash RAM as in cellular phones or beepers. The controller 340 looks for this identification number 360 and updates the display 350 with the information on the attached data stream if a match between the transmitted ID code and the 20 stored identification number 360 is made.

In a preferred embodiment, the display 350 is a low power display. For example, a bistable, non-emissive display, such as an electrophoretic display can be used. In one detailed embodiment, a encapsulated, electrophoretic display, which is inexpensive and easy to manufacture into a finished product, can be used.

25 In one detailed embodiment, the radio-controlled display forms a radio sign that can be updated using information sent via radio-frequency energy. The sign includes a surface covered with a display material and control circuitry. This control circuitry receives broadcast energy. The circuitry decodes the information and updates the sign with that information.

The display material, for example, can be an encapsulated, electrophoretic display or any 30 other encapsulated display material known to those skilled in the art. These display materials can be printed using traditional printing technology, thus facilitating and lowering the cost of sign

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manufacture. Radio signs can be used in stores, airports, train stations, on roads, supermarkets, at conventions, as billboards, or as any other signs where updating the signs or powering the signs may be best done remotely. Content may be updated using any form of electromagnetic radiation. These signs can use solar cells, batteries, or a hardwired source of power. These signs may be in 5 two color, three color, four colors, or full color.

A color display may be fabricated with a multi-step printing process. For example, the first four steps can be a traditional four-color screen printing process to lay down an elaborate border or various static information that will not change throughout the lifetime of the device. The next step can be printing an electronic ink, which may be selected to match exactly the 10 resultant colors from the four-color process. In some embodiments, a top electrode is disposed on the printed electronic ink. The top electrode may also be printed using conventional printing techniques.

In one detailed embodiment, the electronic ink comprises encapsulated electrophoretic ink which includes TiO_2 particles mixed into an organic fluid. The organic fluid, for example, may 15 contain a colored dye. The organic dispersion is emulsified into an aqueous solution and encapsulated using any of known encapsulation procedures known to those skilled in the art. Examples of such materials include gelatin-gum arabic or urea-formaldehyde microcapsules. In this embodiment, the capsules are blended with a binding material to form a printable electronic ink suspension.

20 In another embodiment, a color display may be fabricated using a lamination process. In this embodiment, static information is printed on a first substrate. In this embodiment, the first embodiment includes at least one clear, or substantially clear, aperture. An encapsulated electrophoretic display is laminated to the printed substrate so that the display aligns with the aperture.

25 In another detailed embodiment, a radio-controlled display forms a device capable of receiving broadcast data for individual consumption, referred to herein as a radio paper. The content may be customized for an individual, and a consumer of information could pay for such customized content using an electronic payment scheme. Radio paper may be two-color (e.g. black and white) or full color, as described above. Transactions for content may take place over 30 one or more computer networks, including the world-wide computer network known as the Internet. Referring to FIG. 7, a radio paper 400 includes a substrate 402, a display 404 disposed

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on the substrate 402, a receiver 406 disposed on the substrate 402, and control circuitry 408 disposed on the substrate 402. The display 404 can be printed onto the substrate 402.

Alternatively, flip chip technology can be used to mount a silicon substrate 402 to a display substrate 404. The control circuitry 408 can be created directly on the substrate 402 using low

- 5 temperature poly-silicon process. A plurality of row and column drivers can be interfaced to the backplane of the display 404 for addressing the display 404. In one detailed embodiment, the radio receiver 406 includes traces disposed on the substrate 402. In another detailed embodiment, the radio receiver 406 includes an antenna mounted on the substrate 402. The radio paper 400 can further include a power source 410 disposed on the substrate 402. The power source 410, 10 for example, can be a solar cell, a thin film battery, or a standard cell.

The radio paper described above can be used to provide a wireless updatable document. The device includes: a document cover; an electronic display on any surface of the cover; and a data receiver. The display is fed by data from the data receiver. The display is visible to the document user and represents a way for the document to be messaged subsequent to its delivery.

- 15 15 The device can be provided as a leaflet, book, magazine, circular, periodical, catalogue, directory or item containing a document cover. Ideally the electronic display of the device should operate using very low power and be easily visible. The general class of reflective electronic displays are desirable for this reason. Further ideally the display would be bistable, as described above, in order to minimize power draw. In addition, ideally the display would be flexible and paper-thin to 20 maximize the number of ways in which the display could be incorporated. For example, a paper-thin substrate would allow the radio paper to be addressed by a desktop unit such as a laser printer. Alternatively, the radio paper could be addressed using a stylus that can be passed over the display. An encapsulated electrophoretic display meets all of the stated requirements, and may be used beneficially for this purpose.

- 25 25 The data receiver may be any device capable of receiving information via electromagnetic radiation. In some particular embodiments, the data receiver is a pager or other radio receiver. In other embodiments the data receiver may receive data via a physical connection, such as coaxial cable.

- 30 30 The device may operate by battery power. In this case, the device may incorporate an appropriate sleep mechanism that causes the receiver to only be powered for reception during certain moments of the day when messages are expected to be sent, such as low traffic periods

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where bandwidth is cheaper. The device may also incorporate a solar cell to eliminate or reduce the need for batteries.

An example of the usefulness of this device can be shown by reference to a chain of retail stores that distributes the device as a catalogue. After shipping the catalogue, the retailer may 5 determine certain inventory items must be liquidated. This typically requires costly marketing efforts. Instead, using the device, the chain may advertise the items to be liquidated and may in fact refer the customer to specific pages of the catalogue. The chain may also promote events at the retail store and drive traffic to the store. The chain may also run various messages to different customer segments to evaluate offers and marketing messages on a trial basis.

10 Ideally the device may be addressed either individually or as part of a group of devices. In the former case this permits targeted marketing and in the latter case this saves on bandwidth transmission costs.

15 In still another embodiment, an encapsulated electrophoretic display is used to form a tile display, which allows creation of a large area display by interconnecting a plurality of tile displays. The tile displays, when assembled, may or may not be seamless. Tile pixels may have any shape such as circular, rectangular or other shapes, for example, shapes present in a mosaic font display. There may be a pixel mask applied in front of the pixels.

20 Referring to FIGS. 8A-8D, a tile display system 800 includes a plurality of tile displays 801, 802, 803 and 804 and a controller (not shown). Each tile display 801 includes means for connecting the tile display 801 to an adjacent tile display 802, 803, 804. The tile display system 800 may include any desired number of tile displays. In one embodiment, the tile display system includes 40x30 grid of 16x16 pixel tiles to form a VGA resolution screen.

25 In one detailed embodiment, the tile display system comprises a direct connect structure, that is, each pixel has its own lead line from the controller. Each lead line may be a discrete or packaged transistor line. In this embodiment, a front surface of the substrate comprises of a grid of electrodes, where each electrode is connected through a via to the output of a control chip. Thus, for an $N \times N$ grid, N^2+1 control lines are needed. The additional line is used to connect to a continuous top electrode.

30 A matrix display using $2N+1$ control lines can be built with a plurality of tile displays using a variety of techniques. In one embodiment, an array of varistors, metal-insulator-metal, or discrete diodes are used for individually addressing each pixel. In the case of diodes, discrete,

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surface-mount zener diodes are useful. For an $N \times N$ grid matrix display, using a matrix of two terminal devices, only $2*N+1$ control lines are needed to control the tiles.

In one detailed embodiment, the tiles are connected to each other using standard electronics connectors 805 placed on the edges of the tiles 801 as shown in FIGS. 8A-8D. In 5 another detailed embodiment, the tiles are connected to each other using cables. The tiles can be mounted to a wall, lightweight metal grid, or any other substrate using nuts soldered onto the back of the tiles or by any other means known in the art of fastening substrates.

The controller includes a microprocessor or other suitable drive circuitry. The controller transmits information to the tile displays to update the displays using any convenient form of 10 electromagnetic radiation. In some embodiments the controller also receives information from the tile displays. Data for the display system may be stored in a memory element of the controller or may be received in the form of electromagnetic signals using a receiver. The receiver, for example, can include an antenna and a passive rectifier in communication with the antenna, as described above.

15 In one embodiment, the controller connects to a single tile and controls the entire display. The controller can consist of a battery, a power supply, a paging receiver, and a microprocessor to control the entire system. The display can be powered, for example, using commercially available integrated AC to DC converters. In one embodiment, each tile may have its own high voltage supply. Common inverter chips for use in electroluminescent backlights can be used in 20 this embodiment.

One method of controlling the entire tile system is to have a microcontroller on each tile. In this embodiment, the sign controller tells the one tile it is connected to that it is at a certain coordinate location, say 0,0. Due to the asymmetrical connector layout, the tile can determine to which edge the controller is connected. That tile then communicates with its neighbors, 25 incrementing or decrementing the coordinate location appropriately. Through this protocol, each tile can determine a unique identification code that specifies its location on the sign. The sign controller can then send data out on a common bus and each tile's microcontroller can receive data needed to update the tile. When the appropriate data appears on the bus, the microcontroller shifts this data out to the display drivers. Then, the entire sign is given a write pulse and the entire 30 display is updated. The tile display as described above may be successfully driven with a voltage as low as 3 volts.

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In one embodiment, the tile display is driven by controlling each pixel and the top electrode. To display an image, the electrodes of the backplane are set to the proper pattern of voltages. The rear electrode segments are set at either ground or power and the top electrode is switched rapidly between ground and power. In the state where the top electrode is at power, the

5 areas of the display that have a potential of ground will be addressed and there will be no field elsewhere. When the top electrode is switched to ground, the other areas of the backplane that are at power will be switched. This method allows the backplane to maximize the voltage that the display material will receive. Alternatively, a standard bipolar addressing scheme may be used on the rear electrodes, with the top electrode held at ground potential.

10 In one embodiment, high voltage CMOS display drive circuitry, such as HV57708PG manufactured by Supertex Corporation (Sunnyvale, CA) can be used to drive the tile display. The HV57708PG is an 80 pin plastic gull wing surface mount chip that has 64 outputs. Each output can sink 15mA. Four of these chips can control a single tile. Other chips may find utility in the context of the present invention, such as the Sharp LH1538 which is an 80V 128 line Tape-

15 Automated-Bonding (TAB) chip.

Referring to FIG. 8E, a tile display 830 includes a substrate 831, and a display media 832, electronics 834, and driver circuitry 836. The tile display 830 may be of any convenient size and may have any desired number of pixels. In one embodiment, the tile display 830 is 8 inches by 8 inches, and is a matrix of 16 x 16 pixels. The substrate 831 of the tile display 830 can be: a

20 standard, etched printed circuit board; copper clad polyimide; polyester with printed conductive ink; or any other suitable substrate with patterned conductive areas. A display media 832 such as a encapsulated electrophoretic display media can be printed on a front surface of the substrate. The display media 832 can be a encapsulated electrophoretic suspension consisting of a slurry of capsules in a binder. Each capsule includes a mechanical system consisting of a dielectric

25 suspending fluid and many particles. When an electric field is applied across the capsule, the particles are caused to move in the field. By using two different particle species of different charge and color such as black and white, the viewer can be presented with a color change. In one embodiment, the material is bistable, so that once it is addressed, it stays in its last state. This is used to eliminate power draw between image updates. The material responds purely to the

30 field, thus the only real current draw is in changing the charge of the plates on either side of the material. The capacitance of the display material can be between .1 and 100 picofarads per square

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centimeter. The capacitance will vary with differences in the display material, binder, and overall thickness.

In one detailed embodiment, the display media is printed on a substrate and then covered with a layer of plastic or glass with a clear conductive coating such as ITO-coated mylar.

5 Necessary connections to the ITO can be made using conductive adhesives, contacts, or tapes.

In the embodiment shown in FIG. 8E, the tile display 830 is prepared using the following steps. An electronic ink which forms the display media 832 is coated onto a conductive side of a sheet of ITO-sputtered mylar 835 and then dried or cured. A layer of conductive adhesive 836 is optionally applied to the cured electronic ink 832 forming a laminate. This laminate is adhered to 10 a backplane 837 made of a circuit board having copper pads 838 or a screen-printed metallic inks disposed on its surface. The corners, or one edge 839 of the tile display 830, are reserved to allow connections to be made between the front ITO electrode 833 and the backplane 837. If necessary, the electronic ink 832 is removed from the corners 839 and a connection is made using a conductive adhesive 836 such as silver loaded epoxy or a conductive heat seal.

15 In still another embodiment, encapsulated electrophoretic displays are incorporated into clothing to provide a wearable display. Referring to FIG. 9, a wearable display 502 is embodied as a patch on the arm 504 of a jacket 500 providing weather maps 506 or other information. The wearable display 502 includes a controller 508 in electrical communication with a display monitor 510 comprising a encapsulated, electrophoretic display media and a backplane. The 20 display media is printed onto the backplane. The backplane further includes electronics necessary for addressing the display 502. In some embodiments, the wearable display is in communication with at least one device that provides data for display, such as a global positioning unit, news feed, or a pager. In these embodiments, the data device communicates information to the display which then displays the information for the wearer.

25 Wearable displays can be incorporated into other wearable items such as shoes, socks, pants, underwear, wallets, key chains, shoe laces, suspenders, ties, bow ties, buttons, buckles, shirts, jackets, skirts, dresses, ear muffs, hats, glasses, contact lenses, watches, cuff links, wallet chains, belts, backpacks, briefcases, pocket books, gloves, raincoats, watchbands, bracelets, overcoats, windbreakers, vests, ponchos, waistcoats, or any other article of clothing or fashion 30 accessory.

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In still another aspect, the invention features a communications system. The communications system enables a whole new messaging and communication medium that permits its users to display messages in real time in practically any location.

Referring to FIG. 10, the system 1000 comprises a plurality of display receivers 1002.

- 5 The display receivers 1002 include an electronic display 1004 and a data receiver 1006. In certain embodiments, the display receivers are tile displays or radio papers, as described above. The electronic display 1004 can operate by principles known to the art of LCDs, plasma displays, CRTs, electrophoretic displays or encapsulated electrophoretic displays. The encapsulated electrophoretic display may be coated onto many different surfaces practically any surface using appropriate binders such as PVCs, urethanes and silicon binders, allowing them to be: made in large sizes (such as poster and billboard sizes) using coating techniques; lightweight enough to install without an overhead crane; flexible enough to bend with wind; and capable of holding an image without further power draw, thereby operating economically from solar cells or batteries.
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- 15 The data receiver 1006 may be, for example, a pager, cellular phone, satellite phone, radio-frequency receiver, infrared receiver, cable modem, or any other suitable receiver that is able to receive information from another source. The data receiver 1006 can transmit as well as receive information; for example the data receiver 1006 may transmit verification information to confirm that a new data stream was received. The data receiver 1006 may transmit data as may be useful for the overall operation of the system 1000, for example weather data as part of a
- 20 national weather system. The data receiver 1006 may use varying or multiple transmission methods for both receiving and transmitting data.

- 25 The function of the data receiver 1006 is primarily to receive data and to display text or images in response. The data can include a message, a stream of messages, codes describing how the device should display or transition between the messages, or any other suitable information that will cause the display 1004 to operate as desired by the user. The data can also include a header, error-checking, checksum, routing or other information that facilitates the function of the system 1000.

- 30 In one embodiment, the data receiver 1006 includes a control system 1008. The control system 1008 facilitates the operation of the communications system 1000. In one embodiment, the control system 1008 functions as a user interface that permits the user to design, author, test, collaborate, approve and/or transmit images and commands that are sent to the display receivers.

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In another embodiment, the control system 1008 functions as a billing and authorization system that monitors the user's activity, verifies payment has been received, verifies that the account is in good standing, verifies that the user has proper authorization, creates usage reports, generates invoices, and/or updates data receivers due to unsatisfactory billing status. In another

5 embodiment, the control system 1008 functions as a data receiver management system that tracks data receivers, generates reports of data receiver history and status, permits sorting and screening of data receivers based on suitable characteristics, and/or permits the user to assign messages to the entire network of data receivers or subsets thereof. In still another embodiment, the control system 1008 functions as a data transmission system that pre-processes data into a format suitable
10 for the data receivers or subsets thereof, transmits the data by the method necessary or most suitable for each data receiver, schedules the transmission of the data according to desired criteria, verifies that the data was properly sent, receives and processes any information uploaded from the data receivers 1006, resends messages that may not have been received, generates reports of such activities, and/or generates messages to field personnel indicating potential service requirements.

15 In all of the above embodiments, the control system may utilize the Internet or the World Wide Web as a user interface, as a data transmission mechanism, as an error-checking protocol, as a messaging service, as a programming environment or in any suitable fashion. The control system 1008 may also utilize data encryption mechanisms for enhanced security in the user interaction, in the system operation, in the data receiver transmission or in the data receiver
20 reception. The control system 1008 may also utilize a suitable digital payment scheme to enable funds to be transferred as a part of the overall system of usage and operation.

25 While the invention has been particularly shown and described with reference to specific preferred embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims.

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CLAIMS

What is claimed is:

- 1 1. A method of printing a flexible, electrically active display comprising the steps of:
 - 2 (a) providing a film having a clear electrode structure disposed on a first surface of the
 - 3 film;
 - 4 (b) printing a display media on the first surface of the film, the display media
 - 5 comprising an optoelectrically active material dispersed in a binder; and
 - 6 (c) printing a second electrode covering at least a portion of the display media.
- 1 2. The method of claim 1, wherein step (b) comprises printing an encapsulated
- 2 electrophoretic display media on the first surface of the film, the display media comprising an
- 3 encapsulated, optoelectrically active material dispersed in a binder.
- 1 3. The method of claim 1, wherein step (c) comprises printing an opaque conducting
- 2 electrode covering at least a portion of the display media.
- 1 4. The method of claim 3 wherein step (c) comprises printing a silver ink electrode covering
- 2 at least a portion of the display media.
- 1 5. The method of claim 3 wherein step (c) comprises printing a graphite ink electrode
- 2 covering at least a portion of the display media.
- 1 6. The method of claim 1 wherein step (a) comprises
 - 2 (a-a) providing a film; and
 - 3 (a-b) disposing an electrode structure on the film.
- 1 7. The method of claim 6 wherein step (a-b) comprises printing an electrode structure on the
- 2 film.
- 1 8. The method of claim 1 wherein step (b) comprises printing a display media on the first
- 2 surface of the film, the display media comprising a pigment and an organic polymer mixed into an
- 3 organic fluid.
- 1 9. The method of claim 1 wherein step (a) comprises providing a polymer film having a
- 2 substantially clear electrode structure disposed on a first surface of the film.

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1 10. The method of claim 9 wherein step (a) comprises providing a polyester film having a
2 substantially clear electrode structure disposed on a first surface of the film.

1 11. The method of claim 1 wherein step (b) comprises printing a display media on the first
2 surface of the film, the display media comprising an encapsulated, optoelectrically active material
3 dispersed in a binder, wherein the material is encapsulated in capsules having an average diameter
4 of 100 microns.

1 12. A method of printing a flexible, electrically active display comprising the steps of:

2 (a) providing a first film having an electrode structure disposed on a first surface of
3 the film;

4 (b) printing an encapsulated, optoelectrically active material dispersed in a binder on
5 the first surface of the first film;

6 (c) providing a second film;

7 (d) printing an electrode structure on the second film; and

8 (e) laminating the first film and the second film so that the printed electrode structure
9 is in electrical communication with the encapsulated, optoelectrically active material.

1 13. The method of claim 12 wherein step (a) comprises:

2 (a-a) providing a first film; and

3 (a-b) disposing an electrode structure on the film.

1 14. The method of claim 13 wherein step (a-b) comprises printing an electrode structure on
2 the film.

1 15. The method of claim 12 wherein step (a) comprises providing a polymer film having an
2 electrode structure disposed on a first surface of the film.

1 16. An indicator comprising:

2 a substrate;

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3 a transducer disposed on the substrate; and
4 an encapsulated electrophoretic display printed on the substrate in electrical
5 communication with the transducer, the display displaying an optical state in response to signals
6 from the transducer.

1 17. The indicator of claim 16, wherein the transducer comprises an electrical junction having a
2 current-voltage characteristic that changes as a function of time.

1 18. The indicator of claim 16, wherein the transducer comprises a mechanical system
2 responsive to a change in pressure.

1 19. The indicator of claim 16, wherein the transducer comprises a thermally responsive
2 structure.

1 20. The indicator of claim 16, wherein the transducer comprises a photosensitive structure.

1 21. The indicator of claim 16, wherein the transducer comprises a structure responsive to
2 moisture.

1 22. The indicator of claim 16, wherein the transducer comprises an acoustically responsive
2 structure.

1 23. The indicator of claim 16, wherein the transducer comprises a structure responsive to the
2 orientation of the substrate.

1 24. The indicator of claim 16, wherein the transducer comprises a pH sensor.

1 25. The indicator of claim 16, wherein the transducer comprises a chemically sensitive
2 structure.

1 26. The indicator of claim 16, wherein the transducer comprises a printed structure.

1 27. A battery indicator **for use on** a battery comprising:
2 a printable, electrically **addressable** display in electrical communication with the battery,
3 wherein the display displays **a** first optical state in response to a voltage of the battery.

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1 28. The battery indicator of claim 27, wherein the display displays a second optical state when
2 the voltage applied by the battery falls below a predetermined threshold.

1 29. A battery indicator comprising:
2 an electrophoretic display comprising an encapsulated display media;
3 a first electrode and a second electrode disposed adjacent the electrophoretic display;
4 a nonlinear electrical element in electrical communication with a battery and the first
5 electrode, the nonlinear electrical element conducting a battery voltage to the first electrode when
6 the battery voltage exceeds a predetermined threshold;
7 a voltage divider in electrical communication with the battery and the second electrode,
8 the voltage divider, providing a voltage to the second electrode that is less than the battery
9 voltage; and
10 a resistor in communication with the nonlinear electrical element and the voltage divider.

1 30. The battery indicator of claim 29, wherein the display comprises a capsule including at
2 least one electrophoretic particle and a dye.

1 31. The battery indicator of claim 29, wherein the display comprises a capsule including a first
2 plurality of electrophoretic particles having a first optical property and first electrophoretic
3 mobility distribution and a second plurality of electrophoretic particles having a second optical
4 property and a second electrophoretic mobility distribution.

1 32. The battery indicator of claim 29, wherein the display comprises an encapsulated, bistable
2 display media.

1 33. The battery indicator of claim 29, wherein the voltage divider comprises two
2 high-impedance resistors.

1 34. The battery indicator of claim 29, wherein the nonlinear element comprises a diode.

1 35. The battery indicator of claim 29 further comprising a resistor in electrical communication
2 with the nonlinear device and the second electrode.

1 36. A wearable display comprising:

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2 an article of clothing including an electrically addressable display incorporated into the
3 article of clothing, the display comprising an encapsulated display media; and
4 a controller in electrical communication with the display.

1 37. The wearable display of claim 36, wherein the controller is incorporated into the article of
2 clothing.

1 38. The wearable display of claim 36, wherein the wearable item comprises a fashion
2 accessory.

1 39. The wearable display of claim 36 further comprising a backplane, the display media
2 disposed on the backplane and the backplane in electrical communication with both the display
3 media and the controller.

1 40. The wearable display of claim 36 wherein the wearable display receives data for display.

1 41. The wearable display of claim 40 wherein the wearable display receives global positioning
2 information.

1 42. The wearable display of claim 40 wherein the wearable display receives information from a
2 pager.

1 43. The wearable display of claim 36 wherein the article of clothing comprises a jacket.

1 44. The wearable display of claim 36 wherein the article of clothing comprises a shirt.

1 45. The wearable display of claim 36 wherein the article of clothing comprises a skirt.

1 46. The wearable display of claim 36 wherein the article of clothing comprises a dress.

1 47. The wearable display of claim 36 wherein the article of clothing comprises a briefcase.

1 48. The wearable display of claim 36 wherein the article of clothing comprises gloves.

1 49. The wearable display of claim 36 wherein said electrically addressable display comprises
2 an electrophoretic display.

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1 50. The wearable display of claim 36 wherein said electrically addressable display comprises
2 an encapsulated electrophoretic display.

1 51. An electrically active display tile comprising:
2 a substrate;
3 an electrically addressable display disposed on the substrate, the display comprising an
4 encapsulated display media;
5 a controller disposed on the substrate in electrical communication with the display; and
6 a connector disposed on the substrate for connecting the display tile to another display
7 tile.

1 52. The display tile of claim 51 further comprising a receiver for receiving radio signals, the
2 controller changing the display responsive to received radio signals.

1 53. The display tile of claim 51 further comprising a memory element storing data, the
2 controller changing the display responsive to data stored in the memory element.

1 54. The display tile of claim 51 wherein the substrate has areas of conductivity and areas of
2 nonconductivity.

1 55. The display tile of claim 54 wherein the substrate comprises a printed circuit board.

1 56. The display tile of claim 51 further comprising a substantially transparent electrode
2 dispersed adjacent the display.

1 57. The display tile of claim 56 wherein said substantially transparent electrode is printed onto
2 a substantially clear substrate, said substantially clear substrate subsequently laminated onto said
3 display.

1 58. The display tile of claim 54 wherein the substrate comprises copper-clad polyimide.

1 59. The display tile of claim 51 wherein the display further comprises a clear conductive
2 coating disposed on a first surface of the display.

1 60. The display tile of claim 59 wherein the conductive coating comprises a colloidal
2 dispersion.

- 1 61. The display tile of claim 59 wherein the conductive coating comprises indium tin oxide.
- 1 62. The display tile of claim 51 wherein the connector physically connects the display tile to
2 another display tile.
- 1 63. The display tile of claim 51 wherein the connector electrically connects the display tile to
2 another display tile.
- 1 64. The display tile of claim 51 further comprising an antenna.
- 1 65. The display tile of claim 64 further comprising a passive rectifier in communication with
2 the antenna.
- 1 66. The display tile of claim 65 further comprising an energy storage device in communication
2 with the rectifier.
- 1 67. The display tile of claim 66 further comprising a storage sensor that activates the
2 controller when the energy stored in the energy storage device exceeds a predetermined threshold.
- 1 68. A radio-controlled display comprising:
 - 2 a receiver;
 - 3 a decoder in electrical communication with said receiver; and
 - 4 an electrically active display having an encapsulated display media in communication with
 - 5 decoder.
- 1 69. The display of claim 68 further comprising a power source in connection with the display.
- 1 70. The display of claim 69 wherein the power source is a battery.
- 1 71. The display of claim 69 wherein the power source is a solar cell.
- 1 72. The display of claim 69 wherein the display provides more than two optical properties.
- 1 73. The display of claim 69 further comprising a substrate supporting the display, the receiver,
2 and the decoder, the decoder comprising a series of chips disposed on the substrate.

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- 1 74. The display of claim 69 further comprising a plurality of row and column drivers disposed
- 2 on the substrate for addressing the display.

- 1 75. The display of claim 69 wherein the receiver is disposed on the substrate.

- 1 76. The display of claim 69 wherein the electrically active display comprises a
- 2 microencapsulated electrophoretic display.

- 1 77. The display of claim 69 further comprising an electrically inactive display.

- 1 78. The display of claim 69 further comprising an antennae in electrical communication with
- 2 the control circuit.

- 1 79. A process for creating an electrically addressable display comprising the steps of:
 - 2 (a) providing a substrate; and
 - 3 (b) printing an electrically active ink comprising at least one capsule dispersed
 - 4 in a binder onto a first area of a receiving substrate;- 5 whereby optical qualities of said electrically active ink are modulated responsive to
- 6 received electromagnetic signals.

- 1 80. The process of claim 79 further comprising the step of printing an electrically inactive ink
- 2 onto a second area of the substrate.

- 1 81. The process of claim 79 further comprising the step of printing an electrically inactive ink
- 2 onto a second area of the substrate, wherein the electrically inactive ink has an optical property
- 3 closely matching a corresponding optical property of the active ink.

- 1 82. A process for printing an electrically addressable display, comprising the steps of:
 - 2 (a) providing a substrate; and
 - 3 (b) printing an electrically active ink comprising at least one capsule dispersed
 - 4 in a binder onto a first area of the substrate; and
 - 5 (c) printing an electrically inactive ink onto a second area of the substrate.

1 83. The process of claim 82, wherein step (b) comprises printing an electrically active ink
2 comprising at least one capsule dispersed in a polymeric binder onto a first area of a receiving
3 substrate.

1 84. The process of claim 82, wherein step (a) comprises printing an electrically active ink
2 comprising at least one capsule dispersed in a crosslinked polymeric binder onto a first area of a
3 receiving substrate.

1 85. The process of claim 81, further comprising the step of providing an electrode adjacent the
2 electrically active ink.

1 86. A process for creating an electrically addressable display comprising the steps of:
2 (a) providing a first substrate; and
3 (b) printing an electrically inactive ink onto the first substrate;
4 (c) providing a second substrate;
5 (d) printing an electrically active ink onto the second substrate; and
6 (e) laminating the second substrate and the first substrate to form an
7 electrically addressable display.

1 87. The process of claim 86 wherein step (a) comprises providing a first, substantially clear
2 substrate.

1 88. The process of claim 87 wherein step (b) comprises printing an electrically inactive ink
2 onto the first substrate to form substantially clear apertures in the first substrate.

1 89. The process of claim 88 wherein step (e) comprises laminating the second substrate and
2 the first substrate such that the electrically active ink on the second substrate aligns with the
3 substantially clear apertures formed by the electrically inactive ink.

1 90. The process of claim 86 wherein step (d) comprises printing an electrically active ink onto
2 the second substrate using a four-color process.

1 91. An electrically active sticker display comprising:

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2 an encapsulated display media comprising an optoelectrically active material, the display
3 media having a first surface and a second surface; and
4 an adhesive layer disposed on the first surface of the display media.

1 92. The sticker display of claim 91 wherein a transparent layer is disposed adjacent the second
2 surface of the display media.

1 93. The sticker display of claim 92 wherein the transparent layer includes an electrode.

1 94. The sticker display of claim 92 wherein the transparent layer is conductive.

1 95. The sticker display of claim 92 further comprising a via which extends from the
2 transparent layer to the adhesive layer.

1 96. The sticker display of claim 91 wherein the adhesive layer is conductive.

1 97. The sticker display of claim 91 further comprising at least one electrode disposed on the
2 second surface of the display media with the adhesive layer disposed on the at least one electrode.

1 98. The sticker display of claim 91 wherein the display media comprises an encapsulated
2 electrophoretic display media.

1 99. An electrically active sticker display comprising:
2 a substrate having first and second surfaces;
3 an encapsulated display media comprising an optoelectrically active material disposed on
4 the surface having first and second surfaces of said substrate; and
5 an adhesive layer disposed on the second surface of the display media.

1 100. The sticker display of claim 99 wherein the substrate comprises a polymeric material.

1 101. The sticker display of claim 99 wherein the substrate includes an optically transmissive
2 coating.

1 102. The sticker display of claim 99 wherein the display media comprises a microencapsulated
2 optoelectrically active material dispersed in a binder.

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- 1 103. The sticker display of claim 99 wherein the substrate includes at least one electrode for
- 2 addressing the display media.

- 1 104. The sticker display of claim 99 wherein the display media comprises an encapsulated
- 2 electrophoretic display media.

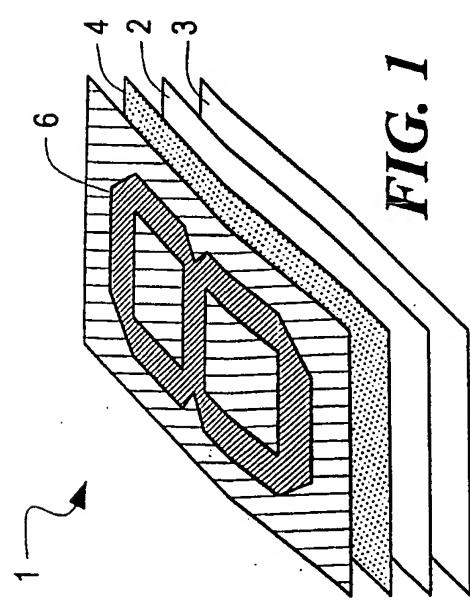


FIG. 1

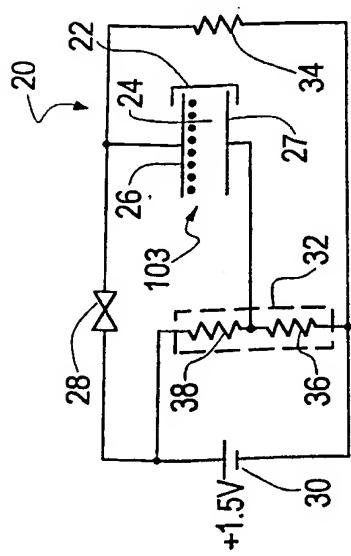


FIG. 3

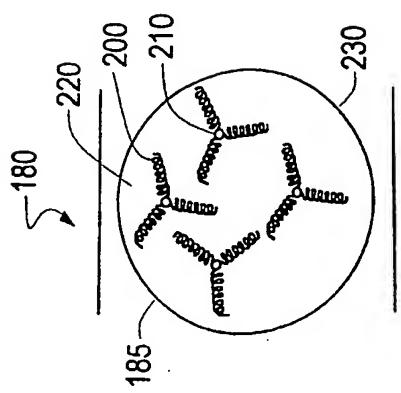
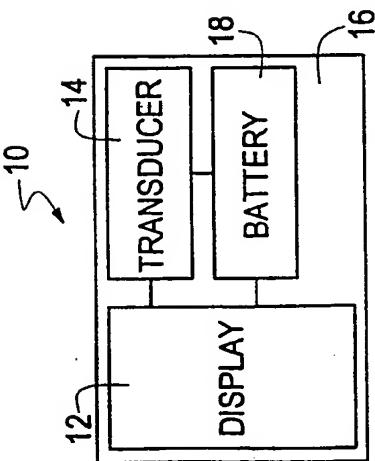
FIG. 4A
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FIG. 2

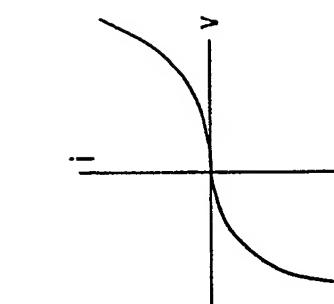


FIG. 3A

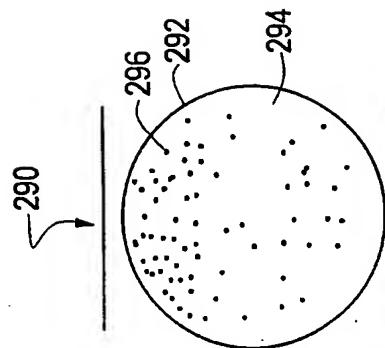


FIG. 4B

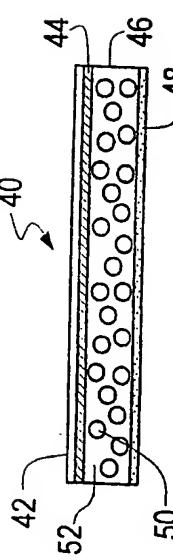


FIG. 5A

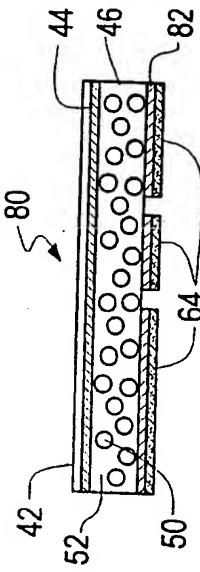


FIG. 5D

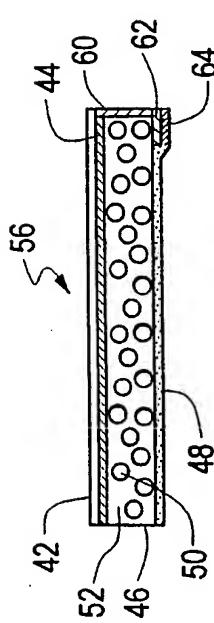


FIG. 5B

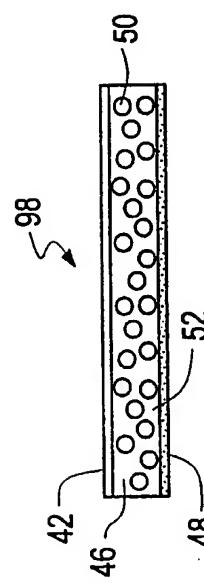
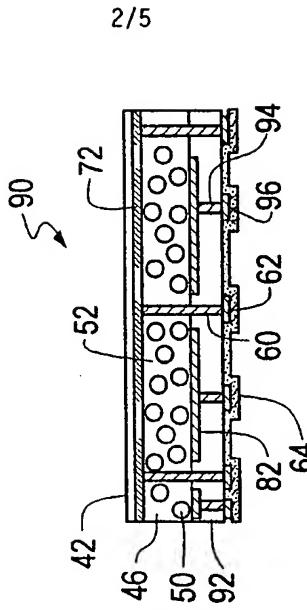


FIG. 5C

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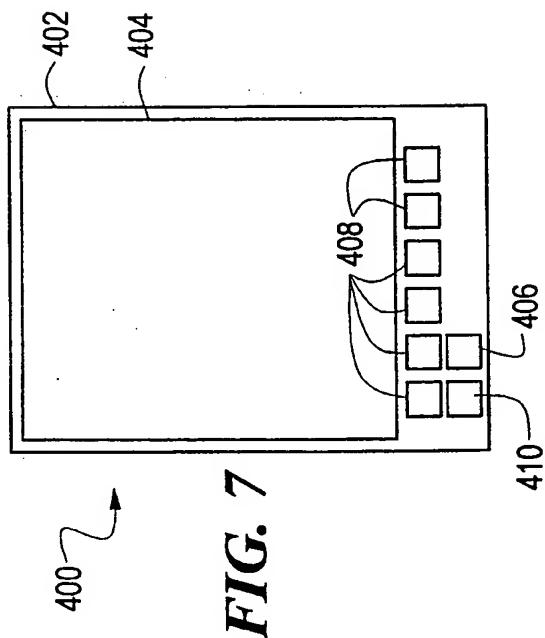


FIG. 7

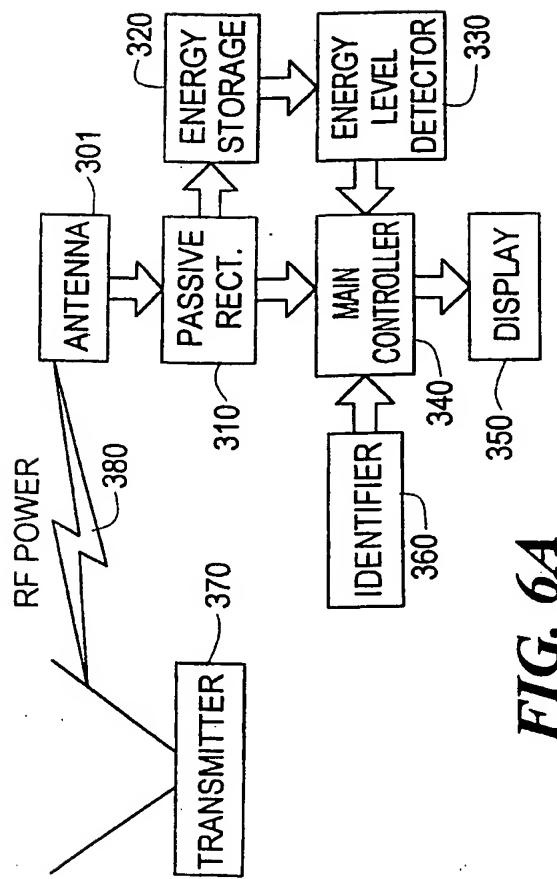


FIG. 6A

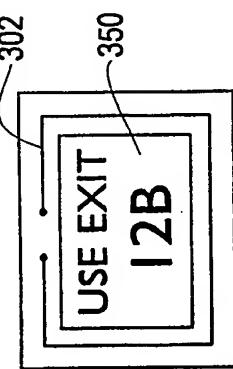


FIG. 6B

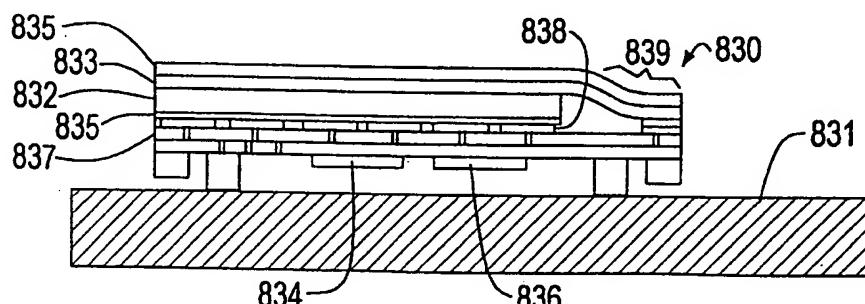
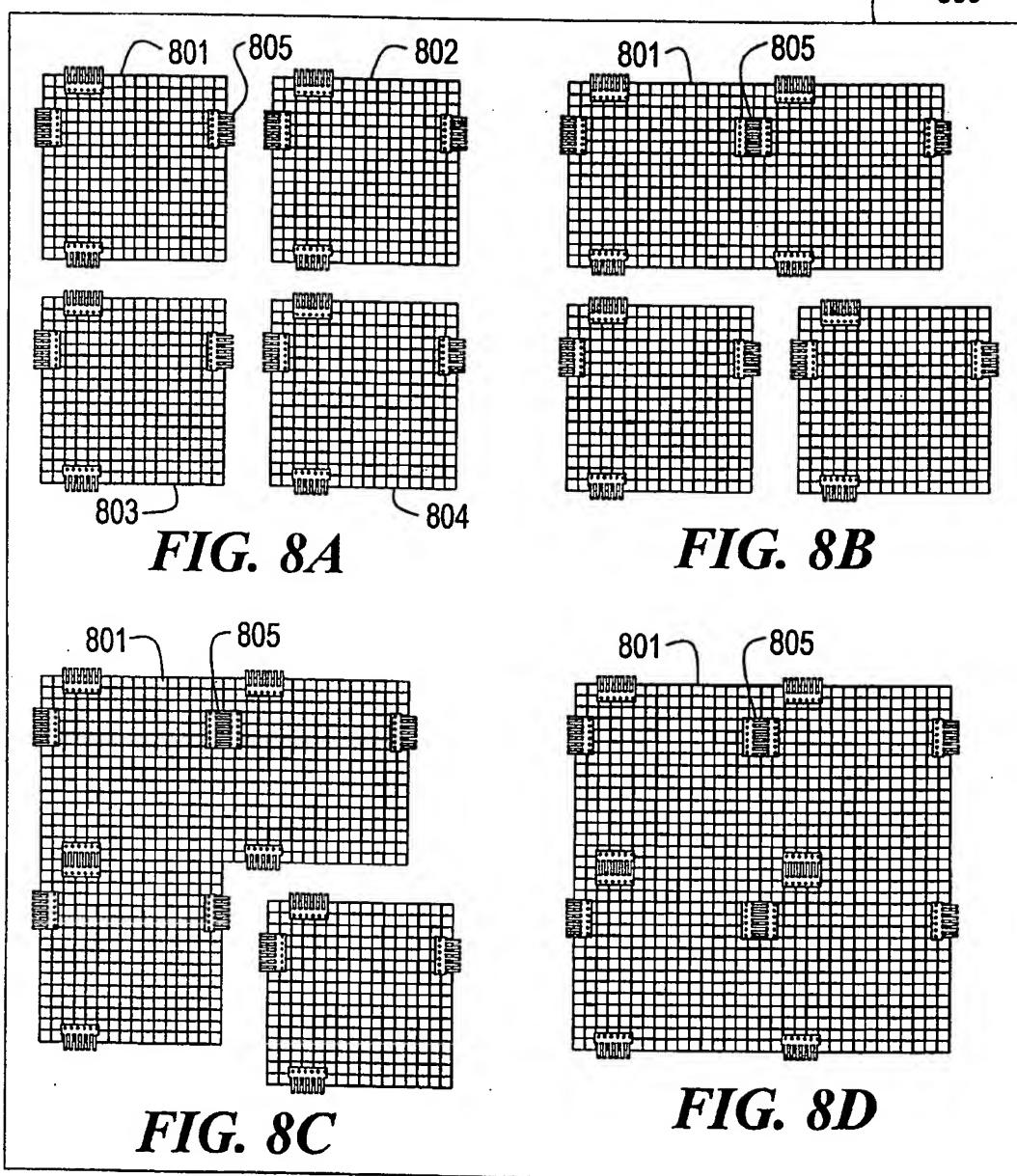


FIG. 8E

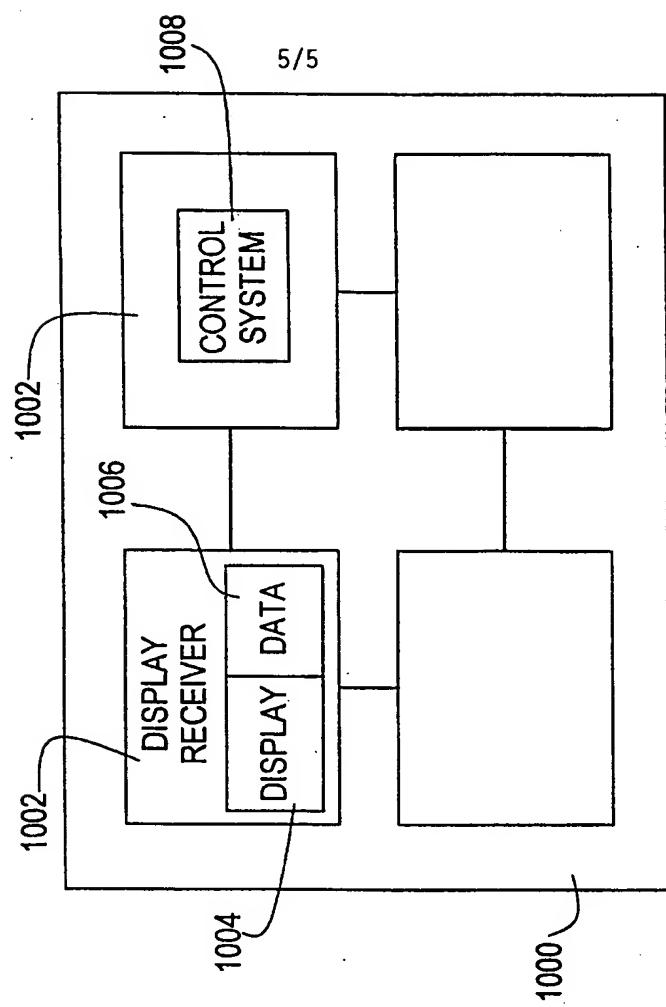


FIG. 10

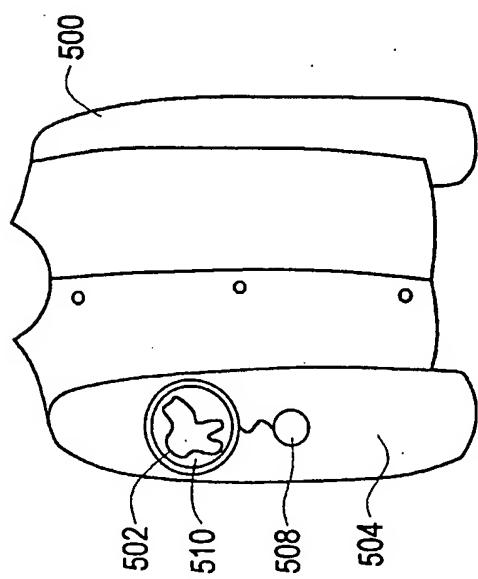


FIG. 9

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 98/17802

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G02F1/167

According to International Patent Classification(IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G02F G03G G09F F21L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 013, no. 316 (P-900), 18 July 1989 & JP 01 086116 A (NIPPON MEKTRON LTD), 30 March 1989 see abstract ---	12,16
P,A	WO 98 19208 A (MASSACHUSETTS INST TECHNOLOGY) 7 May 1998 see page 1, line 1 - line 33 see page 3, line 10 - page 4, line 30 see page 7, line 6 - page 10, line 24 see abstract; figures 1A-5 ---	1-104
P,A	US 5 786 875 A (BRADER LAWRENCE ALLEN ET AL) 28 July 1998 see column 3, line 24 - column 4, line 41; figure 1 ---	1 -/-

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23 November 1998

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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A	US 5 575 554 A (GURITZ STEVEN P W) 19 November 1996 see abstract; figures 1,29-35,38,39 ---	1,36,91, 99
A	PATENT ABSTRACTS OF JAPAN vol. 095, no. 005, 30 June 1995 & JP 07 036020 A (TORAY IND INC), 7 February 1995 see abstract ---	1
A	PATENT ABSTRACTS OF JAPAN vol. 004, no. 149 (P-032), 21 October 1980 & JP 55 096922 A (SHARP CORP), 23 July 1980 see abstract ---	1,12,16, 27,29, 36,51, 68,79, 82,86, 91,99
A	DATABASE WPI Section Ch, Week 9715 Derwent Publications Ltd., London, GB; Class A89, AN 97-161797 XP002085337 & JP 09 031453 A (FUJI PHOTO FILM CO LTD) , 4 February 1997 see abstract -----	1,12,16, 22,29, 36,51, 68,79, 82,86, 91,99

INTERNATIONAL SEARCH REPORT

Information on patent family members				Internal Application No	External Application No
				PCT/US 98/17802	
Patent document cited in search report	Publication date	Patent family member(s)		Publication date	
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US 5786875	A 28-07-1998	NONE			
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		US	5128843 A	07-07-1994	

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